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EXECUTABLE BEHAVIORAL MODELING OF SYSTEM- AND SOFTWARE-ARCHITECTURE SPECIFICATIONS TO INFORM RESOURCING DECISIONS

by

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The size, cost, and slow rate of change of Department of Defense (DOD) Information Technology (IT) systems make introducing new capabilities challenging. Without considering the whole system and its environment, design decisions may result in unintended operational and financial impacts, often not visible until later testing. These complex systems and their interactions are not cheap to maintain, impacting intellectual, programmatic, and organizational resources. Precise behavioral modeling offers a way to assess architectural design decisions prior to, during, and after implementation to mitigate the impacts of complexity, but this modeling cannot estimate those design decisions' effort and cost. This research introduces a methodology to extract Unadjusted Function Point (UFP) counts from architectural behavioral models utilizing a framework called Monterey Phoenix (MP), lightweight formal methods, and high-level pseudocode for use in cost estimation models such as COCOMO II. Additionally, integration test estimates are informed by extracts of MP model event traces. These unambiguous, executable architecture models and their views can be inspected and revised in order to facilitate communication with stakeholders, reduce the potential for software failure, and lower implementation costs.

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The size, cost, and slow rate of change of Department of Defense (DOD) Information Technology (IT) systems make introducing new capabilities challenging. Without considering the whole system and its environment, design decisions may result in unintended operational and financial impacts, often not visible until later testing. These complex systems and their interactions are not cheap to maintain, impacting intellectual, programmatic, and organizational resources. Precise behavioral modeling offers a way to assess architectural design decisions prior to, during, and after implementation to mitigate the impacts of complexity, but this modeling cannot estimate those design decisions' effort and cost. This research introduces a methodology to extract Unadjusted Function Point (UFP) counts from architectural behavioral models utilizing a framework called Monterey Phoenix (MP), lightweight formal methods, and high-level pseudocode for use in cost estimation models such as COCOMO II. Additionally, integration test estimates are informed by extracts of MP model event traces. These unambiguous, executable architecture models and their views can be inspected and revised in order to facilitate communication with stakeholders, reduce the potential for software failure, and lower implementation costs.

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LIST OF ACRONYMS AND ABBREVIATIONS

COA	Course of Action Analysis
COCOMO II	COnstructive COst MOdel II
DET	Data Element Type
DOD	Department of Defense
DODAF	DOD Architecture Framework
EI	External Input
EIF	External Interface File
EO	External Output
EQ	External Inquiry
FFBD	Functional Flow Block Diagram
FP	Function Point
FPA	Function Point Analysis
FPC	Function Point Counting
FTR	File Type Referenced
IFPUG	International Function Point User Group
ILF	Internal Logical File
RET	Record Element Type

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I. OVERVIEW

The Department of Defense (DOD) is in the process of transforming its stove-piped, software-intensive systems into integrated, adaptable, cyber-hardened systems that leverage software, system, and system-of-systems (SoS) engineering techniques.

Historically, there have been significant but often disjointed efforts to develop architectural descriptions that can allow consistent design and analysis of new and legacy systems. Architectural design and analysis are part of a powerful mechanism that captures design decisions early in the process, so they can be assessed and modified without incurring the unnecessary costs of incorrect implementation.

Architectural design decisions are often captured through a system-by-system analysis, using a spectrum of architecture description representations from natural language to formal notations. For this reason, inconsistent architecture descriptions of the system and the environment require analyzing decisions through manually intensive methods, such as inspections and reviews, since the lack of consistent description methods makes automated analysis almost impossible. System development and software architecture development efforts are often implemented as if they were unrelated, with incomplete or duplicative results, yielding technically and programmatically unsustainable outcomes.

This is an unfortunate state of affairs because architecture matters. According to Rozanski and Woods, “every system has an architecture, whether or not it is documented and understood” [1, p. 20]. Architecture deserves the attention of technical and programmatic decision-makers because it can capture design decisions that allows them to verify socio-technical assertions. Without accurate and complete architectural descriptions, the DOD cannot determine disposition strategies for legacy systems (e.g., migrate, sunset), system-development strategies (e.g., buy/adopt/build), interoperability and integration strategies for incremental implementation that inform total cost of ownership (TCO) and return on investment (ROI), and meaningful engineering metrics

that inform forecasting (e.g., estimates of new services or system elements) for future increments of a system's development.

Stakeholders should have complementary interests, but due to incomplete or insufficient architecture representations, their interests often conflict. For example, a software engineer may expect behaviors to be represented by UML sequence diagrams, Agile user stories, high-level pseudocode, or implemented code. A SoS engineer, on the other hand, may want to see functional flow block diagram FFBD boxes and arrows and to search for the conditions that result in emergent behavior. Cost analysts review the resourcing implications for each instance of system and environment architecture, leveraging a spectrum of estimation strategies from Excel through parametric models. Each user wants the system to work from his or her perspective, independent of the healthy tensions between cost and design [2].

To meet these multi-stakeholder challenges, organizations expend significant resources to develop architecture descriptions of an individual system, with only a cursory view of the impact to and from the environment with which it interacts. Architecture descriptions must assist in capturing design decisions, provide a framework to reason about those decisions, and then facilitate analyses to verify assertions early enough in the design process to prevent incurring the costs of incorrect implementation. Cost must be considered a necessary attribute of an architecture element, and software must not be considered an afterthought. These practical requirements can be satisfied by early and consistent behavioral modeling and the extraction of statistics from executable architecture models that inform cost.

A. RESEARCH GOAL

The goal of this research is to introduce a newly developed methodology, called ThreeMetrics, which extracts unadjusted function point (UFP) counts from discrete architecture behavioral models; these models were created from the Monterey Phoenix (MP) modeling language and framework for use in cost estimation models such as Constructive Cost Model II (COCOMO II), protected by copyright [3]–[5]. Additionally, this research discusses the extraction of scenarios (use cases) from the MP model that can

inform distinct integration test cases and the presentation of multiple views for communication with a spectrum of stakeholders. The name ThreeMetrics represents these three metrics: UFP count, use cases to inform integration test estimates, and views of the architecture.

The ThreeMetrics methodology contributes to technical and programmatic decision making by providing the ability to refine and analyze executable architecture models beginning at the earliest design stages.

B. SIGNIFICANCE OF THE PROBLEM AND ITS POTENTIAL IMPACT

Unlike private industry, DOD organizational strategies and resourcing are not directly governed by market influences. A product's time to market and internal programmatic efficiencies do not determine whether a government organization survives through the next quarter.

Senior DOD decision-makers may not understand the mechanics of architecture modeling, but they do understand TCO, ROI, cost savings, cost avoidance, and efficiencies. They understand the need for data that inform their decisions to invest in specific implementations and to quickly and accurately assess whether the ROI is warranted. Decision makers also understand the operational impact on service men and women no matter whether they are still part of the DOD or have transitioned to veteran status.

In the absence of strong influences forcing consistent cultural change across the DOD, enforcement mechanisms, informed by data that are objective, repeatable, timely, and understandable, offer valuable alternatives.

C. SPECIFIC GOALS OF THIS RESEARCH

The ThreeMetrics methodology employs architecture modeling of the behaviors of a software-intensive system, the environment, and the system interacting with the environment, in order to inform technical and investment decisions. This research accomplishes the following:

- Presents a methodology to extract an UFP count from MP's executable architecture models for use in software cost estimation
- Leverages precise behavioral modeling using MP to assess architecture design decisions and their impacts
- Relates architecture modeling to resourcing through analysis of behaviors and UFP counts, leveraging complexity and size metrics such as the data element type (DET)
- Extracts use cases to inform integration testing estimates
- Visualizes results in architecture views, which can be used to communicate with multiple stakeholders

As discussed by Auguston and Whitcomb "The MP behavior model is based on the concept of an event as an abstraction of activity" [3]. MP is an executable architecture model that can be executed on tools to generate examples of the behaviors in the form event traces (use cases). An executable architecture model can be inspected and debugged to test whether the architecture model accurately captures the behaviors of the system.

MP's foundation is in lightweight formal methods, which are essential to behavioral modeling of complex systems because they remove ambiguity from the architecture model. As with all assessments, visual representations and automated tools assist architecture assessments based on lightweight formal methods. Such tools provide immediate feedback, help identify errors once an early architecture draft is constructed, and allow the user to reason about the model. There are many tools that support lightweight formal methods-based analysis, including MP's Analyzer on Firebird [6], Eagle6 [7], and Alloy Analyzer [8]. Firebird and Eagle6 are implementations of the MP framework. Eagle6 is a commercial tool, which has been graciously made available for select research purposes. Firebird is a Naval Postgraduate School (NPS) implementation that is publicly available and was ultimately selected for this research. A more detailed discussion of MP and the tool MP Analyzer on Firebird, or simply Firebird, is included in Chapter II Section E.

This research also leverages the International Function Point User Group (IFPUG)'s counting method, which uses a function point (FP) as the unit of functional size. IFPUG states, "A Function Point is a normalized metric used to evaluate software deliverables and to measure size based on well-defined functional characteristics of the software system" [9]. Function point analysis (FPA) provides a way for measuring software development and maintenance, independent of the technology used for implementation. FPA is viewed from the perspective of the functionality requested by and provided to the user, either a human user or another system. FP descriptions can also help visualize a system, its sub-components, and the environment to address the concerns of specific stakeholders. As such, FPA is an initial step to describing the architecture model of a system.

One of the earliest activities in the FPA counting process is identifying the application boundary. FPA transactional functions can be viewed as markers of this boundary. The ThreeMetrics methodology unambiguously defines the boundaries and interactions of the system and the environment (i.e., everything but the system, including the user) through descriptions in the MP's model schema of the FPA transactional functions. The interactions of the FPA data function types are also represented in the MP's model schema. Once the boundaries are identified and the interactions have been described, the transactional and data function types are extracted from the MP model and complexity value assigned to provide the overall UFP count.

The UFP count is then used as input into COCOMO II to calculate an effort estimate. The MP model is a rich source of information. In addition to extracting a UFP count, the number of use cases to inform integration test estimates and view of the architecture are also extracted from the MP model.

Chapter II of this dissertation presents related work that influenced this research. The ThreeMetrics methodology is then described in Chapter III. The methodology is demonstrated through analyzing three examples in Chapter IV. Chapter V provides a summary of results and findings.

D. PROPOSED ADVANCES TO THE STATE OF THE ART

The ThreeMetrics methodology relates well-established methodologies, such as FP counting and COCOMO II cost modeling, to an executable behavioral modeling of system- and software-architecture specifications.

ThreeMetrics improves on previous state-of-the-art, semi-formal representations used by current function-point-counting methods. By using high-level pseudocode and composition operations from the MP framework, the resulting behavioral architecture model can be iteratively inspected and revised until it represents accurate behaviors.

The precise model of the system- and software-architecture specification includes describing the boundary separating the application under analysis and the environment. If architecture is considered a bridge between the requirements and high-level design, then an architecture model helps to build the correct bridge. The MP model is executed using Firebird, resulting in views of the architecture that are automatically generated. These views establish a "common mental model," a model that all users can interpret, used to communicate with a spectrum of stakeholders.

The development of a precise architecture and commonly understood views early in the product's life cycle reduces the potential for software failure and lowers costs in implementation. This improves on the state-of-the-art by providing a mechanism to execute the representation of both the application and the environment using the same modeling framework, and then automatically generating use cases and scenarios (i.e. views of the architecture model) that serve as examples that humans can understand better than generic descriptions.

The MP model can be inspected manually or by automated tools to extract the number of composition operations that represent the transactional functions and data functions and their associated complexity. Once the UFP count is calculated, it is then inserted into the COCOMO II cost-estimation models to determine effort.

II. RELATED WORK

As discussed in Chapter I, the goal of this research is to develop a methodology to extract UFP counts from executable architectural behavioral models for use in cost-estimation models, such as COCOMO II, to inform effort estimates early in the life cycle of the system. In order to achieve this research goal, the goal itself had to be decomposed into a set of executable research tasks, exploring how mature methodologies and concepts could be linked to create a new methodology. The related works chapter highlights the concepts that established the foundation on which this research was built.

Developing the ThreeMetrics methodology required an understanding of what products would result from applying the methodology to communicate effort estimates early in the life cycle of the system. Sections A through F of Chapter II highlight the following key points that are relevant to this research.

- The scope of effort estimates: For this research, effort estimates included person-month effort, schedule, cost, and integration testing. This led to assessing the COCOMO II model for person-month effort, schedule, and cost and considering inputs that could be used in COCOMO II, such as UFP counts. Section A of this chapter highlights key points about software cost estimation in general, COCOMO II specifically, and introduces the relationship between UFP counts and COCOMO II.

- Unadjusted function point counts: UFP counts are one of several inputs that can be used in the COCOMO II model. UFP counts were selected as the input to COCOMO II for this research. Section B of this chapter addresses FPA, specifically data and transactional functions, and the development of unadjusted FP counts.

- Architecture modeling: UFP counts are developed very early in the lifecycle of the application being counted. Transactional and data functions can be viewed as interactions internal and external to the application being counted. These interactions can be represented in models of the system's architecture. Section C of this chapter addresses architecture modeling.

- Formal, semi-formal, and lightweight formal methods: One of the greatest challenges in system design and development is ensuring that the users' requirements have been satisfied by the implemented application. User requirements are often communicated in natural language, which can be ambiguous. Specificity in the description of the requirements can be achieved using more precise formal descriptions, but the resources needed to create

them can be prohibitive. Section D of this chapter discusses the role of formal, semi-formal, and lightweight formal methods as they relate to this research.

- Monterey Phoenix: Describing the behaviors of an application and the environment with which it interacts can be improved by capturing the behaviors in an executable architecture model, using a modeling language to describe that information, and then using an automated tool to execute the model. The MP modeling language and framework and the MP Analyzer on Firebird were used to describe and execute MP architecture behavioral models. Section E of this chapter provides a description of MP and the aspects of the language and framework relevant to this research.

- Integration test estimates: Integration testing is estimated to represent 25 percent of the total effort associated with an application. The schedule results from the construction phase of the COCOMO II model and the number of event traces generated from the MP model running on Firebird are used to inform integration testing estimates. Section F discusses what integration testing is and the relevance of the scope used in MP Analyzer on Firebird for the generation of the event traces.

Although these topics may be familiar to some readers, they may not be as familiar to others. The reader will be able to explore the references for a more complete description of each term and the associated topic. The combination of these concepts was instrumental in selecting what methodologies would be used in the development of ThreeMetrics, which are discussed in Chapter III of this document.

A. SOFTWARE COST ESTIMATION

There is a range of estimation techniques and algorithmic cost modeling that should be considered when estimating software costs and impacts to schedule. The main cost contributors to a software development project include hardware, software evolution, training, and the effort of software developers. Most practitioners believe that effort is the greatest contributor to overall effort and cost. Quantifying effort is a necessary activity when laying out the resources needed to successfully develop a new software system or enhance an existing one. Two key categories of metrics associated with productivity estimates are size-related metrics and function-related metrics. As noted by Sommerville,

> Productivity estimates are usually based on measuring attributes of the software and dividing this by the total effort required for development. There are two types of metric that have been used:

> 1. Size-related metrics. These are related to the size of some output from an activity. The most commonly used size-related metric is lines of delivered source code. Other metrics that may be used are the number of delivered object code instructions or the number of pages of system documentation.
>
> 2. Function-related metrics. These are related to the overall functionality of the delivered software. Productivity is expressed in terms of the amount of useful functionality produced in some given time. Function points and object points are the best-known metrics of this type.
>
> Lines of source code per programmer-month (LOC/pm) is widely used as software productivity metric. You can compute LOC/pm by counting the total number of lines of source code that are delivered, then divide the count by the total time in programmer-months required to complete the project. This time therefore includes the time required for all other activities (requirements, design, coding, testing and documentation) involved in software development. [10, pp. 615–616]

While LOC/pm is a valuable productivity metric, it can be misleading. If one programmer writes a more concise code than another programmer, or uses a more expressive coding language, the perception of productivity will be inconsistent with reality. An attribute other than coding size needs to be considered. Sommerville, with the contributions of Albrecht and Gaffney, discusses,

> An alternative to using code size as the estimated product attribute is to use some measure of the functionality of the code. This avoids the above anomaly, as functionality is independent of implementation language. The best known function based measure is the function-point count. [10, pp. 615–616]

The activities of the international function point users group (IFPUG) continue to standardize and refine the FP counting methodology initiated by Albrecht, and are discussed in more detail in section B of this chapter. The use of UFP counts in algorithmic cost models is of specific interest to this research. Sommerville explains,

> Algorithmic cost modelling uses a mathematical formula to predict project costs based on estimates of the project size, the number of software engineers, and other process and product factors. An algorithmic cost model can be built by analysing the costs and attributes of completed projects and finding the closest fit formula to actual experience.

In its most general form, an algorithmic cost estimate for software cost can be expressed as:

$$\text{Effort} = A \times \text{Size}^{B} \times M$$

where A is a constant factor that depends on local organisational practices and the type of software that is developed. Size may be either an assessment of the code size of the software or a functionality estimate expressed in function or object points. The value of exponent B usually lies between 1 and 1.5. M is a multiplier made by combining process, product and development attributes, such as the dependability requirements for the software and the experience of the development team. Most algorithmic estimation models have an exponential component (B in the above equation) that is associated with the size estimate. This reflects the fact that costs do not normally increase linearly with project size. As the size of the software increases, extra costs are incurred because of the communication overhead of larger teams, more complex configuration management, more difficult system integration, and so on. Therefore, the larger the system, the larger the value of this exponent. Unfortunately, all algorithmic models suffer from the same fundamental difficulties:

1. It is often difficult to estimate Size at an early stage in a project when only a specification is available. Function-point and object-point estimates are easier to produce than estimates of code size but are often still inaccurate.

2. The estimates of the factors contributing to B and M are subjective. Estimates vary from one person to another, depending on their background and experience with the type of system that is being developed…

A number of algorithmic models have been proposed as the basis for estimating the effort, schedule and costs of a software project. The COCOMO model is an empirical model that was derived by collecting data from a large number of software projects. These data were analysed to discover formulae that were the best fit to the observations. These formulae link the size of the system and product, project and team factors to the effort to develop the system. [10, pp. 615–616]

Table 1 illustrates the primary methods for cost and schedule estimation and the strengths and weaknesses of each, as discussed by Boehm et al. in [11].

Table 1. Estimation Method Comparison. Adapted from [11, p. 226].

Method	Strengths	Weaknesses
Algorithmic Model	Objective, repeatable, analyzable formula Efficient, good for sensitivity analysis Objectively calibrated to experience	Subjective inputs Assessment of exceptional; circumstances Calibrated to past not future
Expert Judgment	Assessment of representativeness, interactions, exceptional circumstances	No better than participants Biases, incomplete recall
Analogy	Based on representative experience	Representativeness of experience
Top-down	System-level focus, Efficient	Less detailed basis, Less stable
Bottom-up	More detailed basis, More stable Fosters individual communication	May overlook system-level costs Requires more effort, less efficient
Unit cost	Cost of purchased or leased facilities, equipment, or supplies	Does not include costing of activity–based services
Activity-based	Cost of labor	Does not include costing of unit-priced services
Price-to-win	Often gets the contract	Generally produces large overruns

As discussed by Boehm et al. “Algorithmic models are based on cost estimating relationship (CER) or schedule estimating relationship (SER) algorithms.” COCOMO II is included in this category and is characterized by Boehm et. al., as one of “fairly general software definition, development, and evolution cost and schedule estimation models” [11, p. 225–226].

COCOMO II was selected for this research because it is a well-documented, well-exercised model, supported by automated tools. The University of Southern California (USC) Center for Systems and Software Engineering (UCSSE) describes the history and current state of the COCOMO II model,

> After several years and the combined efforts of USC-CSSE, ISR at UC Irvine, and the COCOMO II Project Affiliate Organizations, the result is COCOMO II, a revised cost estimation model reflecting the changes in professional software development practice that have come about since the 1970s. This new, improved COCOMO is now ready to assist professional software cost estimators for many years to come. [5]

COCOMO II consists of three sub models: the Applications Composition, Early Design, and Post-architecture models. UFP counts are applicable to both the Early Design and Post-architecture models, and both models are of interest to this research. As described by USCCE,

> COCOMO II provides the following three-stage series of models for estimation of Application Generator, System Integration, and Infrastructure software projects:
>
> 1. The earliest phases or spiral cycles will generally involve prototyping, using the Application Composition model capabilities. The COCOMO II Application Composition model supports these phases, and any other prototyping activities occurring later in the life cycle.
>
> 2. The next phases or spiral cycles will generally involve exploration of architectural alternatives or incremental development strategies. To support these activities, COCOMO II provides an early estimation model called the Early Design model. This level of detail in this model is consistent with the general level of information available and the general level of estimation accuracy needed at this stage.
>
> 3. Once the project is ready to develop and sustain a fielded system, it should have a life-cycle architecture, which provides more accurate information on cost driver inputs, and enables more accurate cost estimates. To support this stage, COCOMO II provides the Post-Architecture model. [4, p. 7]

The counting process for determining the UFP count used in COCOMO II for both the Early Design and Post-Architecture models is consistent with the approach supported by the IFPUG. A combination of UFP and source lines of code is used for the Early Design and Post-Architecture models, leveraging counting rules from the IFPUG for the UFP count. As discussed by UCSSE with contributions from Jones,

> To determine the nominal person months for the Early Design model, the unadjusted function points have to be converted to source lines of

> code in the implementation language (assembly, higher order language, fourth-generation language, etc.) in order to assess the relative conciseness of implementation per function point. COCOMO II does this for both the Early Design and Post-Architecture models by using tables such as those found in [Jones 1991] to translate Unadjusted Function Points into equivalent SLOC. [4, p. 20]

The COCOMO II tool [5] automatically converts UFP counts into source lines of code for a specific implementation language that is an option that can be selected in the tool. This calculation can also be done manually using conversion ratios such as those found in Table 2 from [12], which is an updated version to the table referenced by USCCE in [4, p. 20]. This table includes a SLOC/UFP conversion ratio for the Java language.

Table 2. UFP to SLOC Conversion Ratios. Adapted from [12].

Language	Default SLOC / UFP	Language	Default SLOC / UFP
Access	38	Jovial	107
Ada 83	71	Lisp	64
Ada 95	49	Machine Code	640
AI Shell	49	Modula 2	80
APL	32	Pascal	91
Assembly - Basic	320	PERL	27
Assembly - Macro	213	PowerBuilder	16
Basic - ANSI	64	Prolog	64
Basic - Compiled	91	Query – Default	13
Basic - Visual	32	Report Generator	80
C	128	Second Generation Language	107
C++	55	Simulation – Default	46
Cobol (ANSI 85)	91	Spreadsheet	6
Database – Default	40	Third Generation Language	80
Fifth Generation Language	4	Unix Shell Scripts	107
First Generation Language	320	USR_1	1
Forth	64	USR_2	1
Fortran 77	107	USR_3	1
Fortran 95	71	USR_4	1
Fourth Generation Language	20	USR_5	1
High Level Language	64	Visual Basic 5.0	29
HTML 3.0	15	Visual C++	34
Java	53		

In COCOMO II, a development effort estimate is in person months (PM). As described by USCCE in the COCOMO II Model Definition Manual v. 2.1, including contributions from Banker et al.,

> The nominal effort for a given size project and expressed as person months (PM) is given by …

$PM_{nominal} = A \times (Size)^B$ …

> [This equation] is the base model for the Early Design and Post-Architecture cost estimation models. The inputs are the Size of software development, a constant, A, and a scale factor, B. The size is in units of thousands of source lines of code (KSLOC). This is derived from estimating the size of software modules that will constitute the application program. It can also be estimated from unadjusted function points (UFP), converted to SLOC then divided by one thousand. Procedures for counting SLOC or UFP are explained in the chapters on the Post-Architecture and Early Design models respectively. The scale (or exponential) factor, B, accounts for the relative economies or diseconomies of scale encountered for software projects of different sizes The constant, A, is used to capture the multiplicative effects on effort with projects of increasing size. [4, p. 7]

A more detailed discussion of the UFP count, its relationship to SLOC, and its use in COCOMO II is found in Chapter III, Methodology, and Chapter IV, Implementation.

B. FUNCTION POINT COUNTING PROCESS

In the late 1970s, Allan Albrecht from IBM was the first person to publicly describe FPA as a method for functionally sizing software. The IFPUG was formed in 1986. While there are many companies that promote minor variations on the FP counting process, IFPUG has been viewed as the authoritative source of information with respect to this research. As described by the IFPUG [13] on its website,

> The International Function Point Users' Group (IFPUG) is a non-profit, member governed organization. The mission of IFPUG is to be a recognized leader in promoting and encouraging the effective management of application software development and maintenance activities through the use of Function Point Analysis (FPA) and other software measurement techniques.

The IFPUG website is a valuable resource for FPA information, professional certifications, educational opportunities, conferences, committees, and working groups. The IFPUG's *Function Point Counting Practices Manual* contains the definitions and the FP counting methodology used as the baseline for this research. The IFPUG information was augmented, with contributions from FP counting practitioners, to understand how the

methodology is used in practice. Although there is variability in the opinions, interpretations and refinements of the IFPUG FP counting methodology, the basic concepts from that baseline are still consistently understood and implemented in tools and practice. Additionally, there are descriptions, tutorials, and papers from practitioners, each offering their own perspective on how to interpret the functional requirements and apply the counting methodology [13]–[17].

The IFPUG provides the following definition, “Function Points are an internationally standardized unit of measure used to represent software size. The IFPUG functional size measurement method (referred to as IFPUG 4.3.1) quantifies software functionality provided to the user based solely on its logical design and functional requirements” [13].

For all the promoters and benefits associated with FPA, there are also detractors and drawbacks. As derived from Kemerer [18] and Low and Jeffery [19] and stated by Fraternali et al.,

> It is well known that calculating the function points associated with a system is a labor intensive, time consuming and imprecise task. Organizations need experienced personnel dedicated to function point analysis, a substantial tuning period, and a large project base before reaching accurate predictions… In other words, much the same problems occurring in manual implementation of software affect also the manual computation of the software size. [20]

Yet, FP descriptions can be considered ways to view a system and its input and output activities, with the primary focus on addressing concerns of stakeholders at the outset.

Data function and transactional function types are foundational terms in the FPA community as is the concept of the users’ perspectives. For the purposes of FPA, a user can be a human or another machine interacting with the software. As discussed by the IFPUG in [9], the well-documented process to perform a FP count includes the following steps:

- Gather available source information
- Determine the counting scope and boundary

- Count data function and transactional function types
- Determine the unadjusted FP count
- Determine the value adjustment factor
- Calculate the final adjusted FP count

One of the earliest steps in the FPA counting process is identifying the counting scope (e.g., new application, modification to an existing application), and the application boundaries (e.g., what is the application of interest being considered for the count and what is not). As discussed by IFPUG,

> Function point counts can be identified, based on their purpose, as one of the following:
>
> - Development project function point count
> - Enhancement project function point count
> - Application function point count [9, Sec.2-4]

IFPUG also clearly defines the boundary of the application being counted, to distinguish it from the environment:

> The boundary is a conceptual interface between the software under study and its users. The boundary (also referred to as application boundary):
>
> - Defines what is external to the application.
> - Indicates the border between the software being measured and the user.
> - Acts as a ‘membrane’ through which data processed by transactions (EIs, EOs and EQs) pass into and out from the application.
> - Encloses the logical data maintained by the application (ILFs).
> - Assists in identifying the logical data referenced by but not maintained within this application (EIFs).
> - Is dependent on the user’s external business view of the application. It is independent of technical and/or implementation considerations. [9, Sec. 5-4]

Figure 1 illustrates key concepts associated with FP counting and analysis: application boundary containing the application being considered, the transactional functions (External Input-EI, External Output-EO, External Inquiry-EQ), the data functions (Internal Logical File-ILF, External Interface File-EIF), and a User sitting in front of his computer.

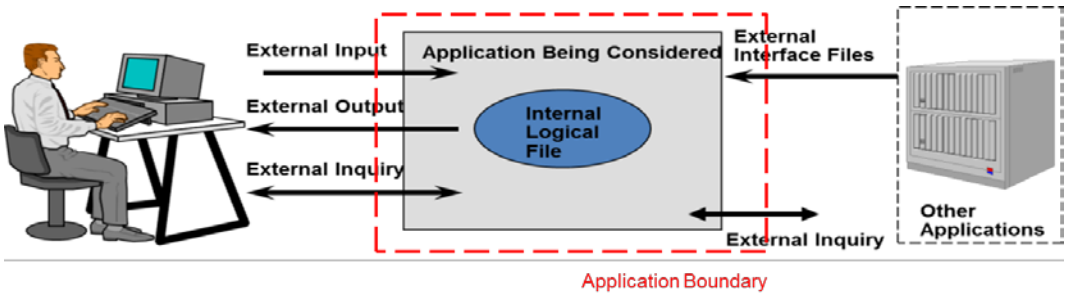

Figure 1. Functionality as Viewed from the User's Perspective.
Adapted from [21].

The IFPUG provides the following definitions in [9], which support the concepts illustrated in Figure 1:

> An external interface file (EIF) is a user recognizable group of logically related data or control information, which is referenced by the application being measured, but which is maintained within the boundary of another application… [9, Sec.6-2]
>
> An internal logical file (ILF) is a user recognizable group of logically related data or control information maintained within the boundary of the application being measured… [9, Sec.6-2]
>
> An elementary process is the smallest unit of activity that is meaningful to the user… [9, Sec.6-3]
>
> A data function represents functionality provided to the user to meet internal and external data storage requirements. A data function is either an internal logical file or an external interface file… [9, Sec.6-4]
>
> Assign each identified ILF and EIF a functional complexity based on the number of data element types (DETs) and record element types (RETs) associated with the ILF or EIF. This section defines DETs and RETs and includes the rules for each… [9, Sec.6-5]

> A data element type (DET) is a unique, user recognizable, non-repeated attribute… [9, Sec.6-5]
>
> A record element type (RET) is a user recognizable sub-group of data element types within a data function… [9, Sec.6-7]
>
> A transactional function is an elementary process that provides functionality to the user to process data. A transactional function is an external input, external output, or external inquiry… [9, Sec.7-1]
>
> An external input (EI) is an elementary process that processes data or control information sent from outside the boundary… [9, Sec. 7-3]
>
> An external output (EO) is an elementary process that sends data or control information outside the application's boundary and includes additional processing beyond that of an external inquiry… [9, Sec.7-3]
>
> An external inquiry (EQ) is an elementary process that sends data or control information outside the boundary… [9, Sec.7-3]
>
> A file type referenced (FTR) is a data function read and/or maintained by a transactional function… [9, Sec.7-14]

Practitioners often expound upon the definitions of the original IFPUG terms. Longstreet in [15] provides a practitioner's view of transactional and data function types, and describes key words in natural language that are associated with data functions and transactional functions. FTRs, RETs, and DETs are important because their count influences the functional complexity and, by extension, the functional size used to calculate the unadjusted FP count for each transactional or data function. The summation of the UFP count for each data function and each transaction function results in the overall UFP point count. Functional complexity and size are identified for each ILF, EIF, EI, EO, and EQ, in Tables 3, 4, 5, 6, and 7, based on values captured from the IFPUG [9]. These tables are used in the calculation of the UFP counts in Chapters III and IV of this dissertation.

Table 3 contains the functional complexity and size values used to determine the UFP count for an EI.

Table 3. Functional Complexity and Size for EIs. Adapted from [9, Sec. 1, p. 19 Table 6 and 8].

External Inputs: EI

	1 to 4 DETs	5 to 15 DETs	16 or more DETs
0 to 1 FTRs	Low	Low	Average
2 FTRs	Low	Average	High
3 or more FTRs	Average	High	High

External Inputs EI

Functional Complexity Rating	Function Points
Low	3
Average	4
High	6

Table 4 contains the functional complexity and size values used to determine the UFP count for an EQ.

Table 4. Functional Complexity and Size for EQs. Adapted from [9, Sec.1, p. 19, Table 7 and Table 8].

External Inquiries: EQ

	1 to 5 DETs	6 to 19 DETs	20 or more DETs
0 to 1 FTRs	Low	Low	Average
2 to 3 FTRs	Low	Average	High
4 or more FTRs	Average	High	High

External Inquiries: EQ

Functional Complexity Rating	Function Points
Low	3
Average	4
High	6

Table 5 contains the functional complexity and size values used to determine the UFP count for an EO.

Table 5. Functional Complexity and Size for EOs. Adapted from [9, Sec.1, p. 19, Table 7 and Table 8].

External Outputs : EO

	1 to 5 DETs	6 to 19 DETs	20 or more DETs
0 to 1 FTRs	Low	Low	Average
2 to 3 FTRs	Low	Average	High
4 or more FTRs	Average	High	High

External Outputs: EO

Functional Complexity Rating	Function Points
Low	4
Average	5
High	7

Table 6 contains the functional complexity values used to determine the UFP count for an ILF and EIF.

Table 6. Functional Complexity for ILF and EIF. Adapted from [9, Sec.1, p. 13 Table 1].

	1 to 19 DETs	20 to 50 DETs	51 or more DETs
1 RET	Low	Low	Average
2 to 5 RETs	Low	Average	High
6 or more RETs	Average	High	High

Table 7 contains the functional size values used to determine the UFP count for an ILF and EIF.

Table 7. Functional Size for Data Functions. Adapted from [9, Sec. 1, p. 13, Table 2].

ILF Translation Table: Use the following table to assign a functional size to each ILF.

Functional Complexity Rating	Function Points
Low	7
Average	10
High	15

ILF

EIF Translation Table: Use the following table to assign a functional size to each EIF.

Functional Complexity Rating	Function Points
Low	5
Average	7
High	10

EIF

Examples of UFP calculations using these tables are provided in Chapters III and IV. Once the total UFP count has been calculated, the adjusted FP Count can be calculated using the value adjustment factor (VAF). For the purpose of this research, the UFP was used in lieu of the adjusted FP count because the UFP count is an input for sizing in the COCOMO II model. As explained by Boehm et al., from a collection of his works edited by Selby,

> Each instance of these function types is then classified by complexity level. The complexity levels determine a set of weights which are applied to their corresponding function point counts to determine the Unadjusted Function Points quantity. This is the Function Point sizing metric used by COCOMO 2.0. The usual Function Point procedure involves assessing the degree of influence of fourteen application characteristics on the software project determined according to a rating scale of 0.0 to 0.05 for each characteristic. The fourteen ratings are added together, and then added to a base level of 0.65 to produce a general characteristic adjustment factor that ranges from 0.65 to 1.35. Each of these fourteen characteristics, such as distributed functions, performance, and reusability, thus has a maximum 5% contribution to the estimated effort.
>
> This is significantly inconsistent with COCOMO experience; thus, COCOMO 2.0 uses Unadjusted Function Points for sizing, and applies its reuse factors, cost driver effort multipliers, and exponent scale factors to this sizing quantity. [22, p. 281–282]

At a high level, it appears that the goal of the IFPUG and the FPA methodology is to provide structure and consistency in ambiguity, creating a bridge between functional requirements and high level design, independent of implementation language. In effect, this bridge is an architectural model of the software system being counted, so that the attributes of the system, as seen from the perspective of the user, can be represented in a way that other FP counters can understand.

FP descriptions can then be considered a way to view the behaviors of a system through its input and output activities, i.e. its interactions. These behaviors can be described with greater specificity using a Monterey Phoenix executable architecture model.

An event in MP is an abstraction of an activity within a system. An elementary process represents the smallest unit of activity in a system. A transactional function is an

elementary process. The behavior of a transactional or data function can be described in an MP architecture model as an abstraction of an interaction, by using high-level pseudo-code. The functional aspects of requirements can then be represented in a way that is amenable to incremental refinement.

The composition operations COORDINATE and SHARE ALL can be viewed as markers of an interaction in the MP model. The structure and the complexity of interactions in MP provide a source for assigning functional complexity and size values to the UFP count. These values are consistent with the functional complexity and functional size values associated with DETs, RETs, and FTRs in the function point counting methodology.

Since an MP model is precise and formal, FP metrics can be extracted from the model by using automated tools, to support cost estimates early in the life cycle of an application. A more detailed discussion of software architectures and software architecture modeling is in Chapter II Section C; a more detailed discussion of MP can be found in Chapter II Section E; their relationship is described in the ThreeMetrics methodology in Chapter III.

C. ARCHITECTURE AND ARCHITECTURE MODELING

The implementation of a software system is a socio-technical endeavor. As such, the system's purpose and relevance have to be communicated to multiple stakeholders in a way that hides its complex detail but retains its key characteristics. This can be achieved through the model of the architecture of a system and the environment with which it interacts. An architecture model is an abstraction that is used to reason about what the real system and environment will be. The model can be manipulated and presented in such a way as to abstract away detail until needed, at which point incremental refinement of the architecture shines a light on the approach to design and implementation.

Yet, 'architecture' is one of the most overused, misused, and disrespected words in the DOD vocabulary. Rather than viewing architectural analysis and architecture modeling as powerful tools to establish a "common mental model" of a system across a

spectrum of stakeholders, models of architectures are viewed as check-the-block requirements for acquisition milestones and DOD directives. The notations and tools are considered, in many cases rightly so, oversold promises that, in actuality, require an expensive shadow workforce for their creation and maintenance, with a fraction of return on investment. This is an unfortunate situation that has evolved due to cottage-industry mentality, and the demands of well-meaning bureaucratic processes.

The model of the architecture of a system and the environment with which it interacts is the single most important artifact that an organization can have. The model contributes to the following activities:

- Unifying an organization
- Eliciting and confirming what the user wants
- Assigning organizational responsibilities and informing resourcing decisions across organizations
- Exploring high level design decisions
- Positioning for development
- Executing developmental, integrated, and operational testing
- Supporting deployment into production
- Controlling software evolution in sustainment

Perhaps the sticking point is the multitude of definitions of the terms that are directly and indirectly associated with the words ‘architecture’ and ‘architecture model’, including ‘system’, ‘software system’, ‘application’, ‘software architecture’, ‘system architecture’, ‘environment’, ‘system-of-systems’, ‘socio-technical systems’, ‘software architecture models’, and ‘modeling notations.’ There are many definitions available across multiple disciplines; only those that are relevant to and have influenced this research follow.

In software engineering and architecture literature, the terms ‘application’ and ‘system’ are often assumed to be used interchangeably. Practitioners will argue that an implemented system must not only include the application, but also its target computing

platform. The definition is often then expanded to include data, people, and processes, depending on the reference point of the practitioner.

The IFPUG throughout [9] appears to use the terms ‘application’ and ‘system’ interchangeably.

Pfleeger and Atlee describe a system as “a collection of things: a set of entities, a set of activities, a description of the relationships among entities and activities and a definition of the boundary of the system” [23, p. 17].

Rozanski and Woods describe a computer system as “the software elements that you need to specify and/or design in order to meet a particular set of requirements and the hardware you need to run those software elements on” [1, p. 11].

Rechtin defines a system as “A set of different elements so connected or related as to perform a unique function not performable by the elements alone” [24, p. 7]. For the purposes of this research, the environment is everything but the system under analysis. The environment can be another system or a system of systems. The user is considered part of the environment with which an application interacts.

The Department of Defense Architecture Framework (DODAF) describes a system as “a functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements” [25].

Sommerville defines a system as “a purposeful collection of interrelated components that work together to achieve some objective” [10, p. 21]. Sommerville introduces technical computer-based systems and socio-technical systems, and describes the key characteristics of a socio-technical system:

> emergent properties that are properties of the system as a whole rather than associated with individual parts of the system. Emergent properties depend on both the system components and the relationships between them…
>
> They are often nondeterministic. This means that when presented with specific input, they may not always produce the same output…

> Furthermore, use of the system may create new relationships between the system components and hence change its emergent behavior. [10, p. 21–22]

As an addition to these definitions, Conway states “Any organization that designs a system (defined more broadly here than just information systems) will inevitably produce a design whose structure is a copy of the organization's communication structure” [26].

Although there are no globally agreed to definitions of a system of systems, Vaneman and Jaskot suggest that it is “a set or arrangement of systems that results when independent and task-oriented systems are integrated into a larger systems construct, that delivers unique capabilities and functions in support of missions that cannot be achieved by individual systems alone” [27].

Sommerville’s definitions associated with a socio-technical system are most relevant to a practitioner’s experience with software, particularly the inclusion of interaction with a human user and the reality of emergent behavior. However, since using the qualifier ‘socio-technical’ to describe a system is often not well received, ‘software system’ is still the term of choice.

The relationship between a system, the architecture of a system, and an architecture model of a system is confusing. Rozanski and Woods state “Every system has an architecture, whether or not it is documented and understood” [1, p. 20].

The challenge practitioners often face is interpreting the architecture of an existing system and environment, or the model of an architecture of a new system or enhancement to an existing system. Often, the artifacts describing them have been documented incorrectly, incompletely, or not documented at all. For an existing system, the architecture may be recovered from implementation artifacts, but that is not a simple task. Maier and Rechtin define an architecture as “The structure—in terms of components, connections, and constraints—of a product, process, or element” [28, p. 415].

Rozanski and Woods reiterate the ISO/IEC 42010 definition of architecture, which is expanded to address the influences of environment: “The architecture of a system is the set of fundamental concepts or properties of the system in its environment, embodied in its elements, relationships, and the principles of its design and evolution” [1, p. 12].

DODAF does not explicitly define the term ‘software system architecture’ or its environment, but the framework and views can be used to describe the architecture of a system that includes software and software services.

As suggested by Taylor et al. “A software system’s architecture is the set of principal design decisions made about the system” [29, p. 58].

When considering the software architecture of a system and environment, identifying what to abstract away or hide is as much an art as a science. Bass et al. explain:

> an architecture is first and foremost an abstraction of a system that suppresses details of elements that do not affect how they use, are used by, relate to, or interact with other elements. In nearly all modern systems, elements interact with each other by means of interfaces that partition details about an element into public and private parts. Architecture is concerned with the public side of this division; private details-those having to do solely with internal implementations—are not architectural. [30, p. 21]

This definition was very interesting, as it begs the question, what is private versus what is public? How and where is the boundary drawn for the system under analysis, when there is some confusion as to the definition of the system? Is it an arbitrary boundary? In the absence of a definitive architecture, cyber artifacts that describe the accreditation boundary of a system are useful tools, to support the steps needed to recover the architecture of the internal components.

Once a software system is imagined, the next focus is to define it through a model of its architecture. Taylor et al. describe an architectural model as

> an artifact that captures some or all of the design decisions that comprise a system's architecture. Architectural modeling is the reification and documentation of those design decisions…
>
> A software systems architecture is captured in an architectural model using a particular modeling notation. An architectural modeling notation is a language or means of capturing design decisions. [29, p. 185]

In the current practice, a new system or capability may be introduced into an existing environment, resulting in unexpected behaviors requiring corrective action that has a resourcing impact. Software engineers and architects need to be able to analyze the new system and existing environment in order to advise program managers about the impacts to cost, schedule, and operations. Architectural modeling offers a way to assess architectural design decisions and their impacts prior to, during, and after implementation and deployment.

A model of an architecture should not be confused with the architecture itself. As discussed by the Object Management Group:

> A model is always a model *of* something. The thing being modeled can generically be considered a system within some domain of discourse. The model then makes some statements of interest about that system, abstracting all the details of the system that could possibly be described, from a certain point of view and for a certain purpose. [31]

Monterey Phoenix describes the architecture model of a system and the environment with which it interacts in terms of behaviors: the behaviors of components of the software system, the behaviors of the interactions between the components, the behaviors of the environment with which it interacts, and the behavior of its interaction with the environment [32]–[34].

Techniques used in software system design, such as abstraction and encapsulation, are directly applicable to the architecture model of a system and its environment. As discussed in Pfleeger and Atlee and derived from Berard:

> However, encapsulation is not the same as information hiding… abstraction is a technique that helps us identify which specific information should be visible, and which information should be hidden. Encapsulation is then the technique for packaging the information in such a way as to

> hide what should be hidden, and make visible what is intended to be visible [23, p. 290].

Seidewitz offers a perspective on model-driven development, discussing definitions of models, metamodels, and model interpretation leveraging unified modeling language (UML) terms to describe models of software, specifically the system under study (SUS) [35].

Selic highlights the necessity of model execution, stating that "one important advantage of executable models is that they provide early direct experience with the system being designed" [36].

These become very useful techniques when establishing the boundary of an application under analysis, and deciding what information to abstract and how to do so.

The development of an architecture model starts with understanding what the user wants, i.e., his or her requirements, and then creating a representation of those requirements in architecture models and extracting views that answer questions from stakeholders, including the user. Pfleeger and Atlee state that "A requirement is an expression of desired behavior" [23, p. 143]. A system's required behaviors can be modeled in MP to confirm that the requirements communicated by the stakeholders have been satisfied.

Pfleeger and Atlee also highlight that "the architecture of a system is the interface between required capabilities in a specification and the implemented system" [23, p. 229]. Stakeholders communicate their concerns through requirements, another word that elicits strong reactions. 'Requirements' is an umbrella term that captures functional, non-functional, derived, technical, as well as variations of the meaning of each one of these terms. Once the term 'requirement' is sufficiently clear, then the process of iterating between the users and the technical team can begin, followed by employing methodologies to reason about the design and implementations options. Pfleeger and Atlee state that

> a functional requirement describes required behavior in terms of required activities such as reactions to inputs and state of each entity before and after an activity occurs…
>
> The functional requirements define the boundaries of the solution space for our problem.
>
> A quality requirement or non-functional requirement describes some quality characteristic the software solution must possess, such as fast response time, ease of use, high reliability, or low maintenance cost. [23, p. 148–149]

Once initial functional user requirements are captured, the process of specifying what the software system will do in terms of tasks and services begins, resulting in an architectural representation of the system. This iterative process is best served by modeling the architecture.

A software engineer or developer will find behaviors as represented by pseudocode, sequence diagrams or use cases necessary to translate the user requirements into implemented code. Cost analysts will want to understand what each instance of the architecture at a point in time would cost (from requirements elicitation through software evolution) and document those resourcing implications in a life cycle cost estimate, or year of execution spend plan. Testers can leverage architectures to identify what are optimal instrumentation points and what test cases and strategies are necessary for development, integration, and operational testing. The program manager must ensure that both user and acquisition expectations are being met by applying cost and management controls. As illustrated in Table 8, each stakeholder has his or her own interests and needs views to assist in understanding the architecture.

Table 8. Architecture: A Bridge between Requirements and High-Level Design.

Stakeholder Examples	Typical Questions and Views That Inform The Answers
Customer	Are user, technical, cost, and management expectations being met? (e.g. Box and Arrow Diagrams and Sequence Diagrams with $ and Assigned Organizational Responsibilities, Schedule)
Users	Does this system do what was expected? Does it fulfill prioritized requirements? (e.g. Prototype of Screens, User Stories, Sequence Diagrams)
Engineers / Designers	What implementation option(s) should be considered to meet user performance expectations? What are environment interactions and constraints for each option? (e.g. Sequence Diagrams, Use Cases, Pseudocode of Behaviors)
Testers	What are optimal instrumentation points? What statistics should be gathered? What is the correct level of architectural abstraction? (Instrumentation Points, Code, Logs, Test Cases)
Cost Analysts	What is the cost of the system from requirements elicitation thru software evolution? (LCCE, Spend Plan, Cost Model Results)

Simple box and arrow diagrams, and sequence diagrams are often sufficient to assist with understanding cost, organizational responsibility, and schedule impacts. The users just want the system to work, as they have imagined. A prototype of screens, user stories, and sequence diagrams are supportive of iteratively refining their requirements. Extracting the appropriate information from architecture to support communication with multiple stakeholders is always a challenge because it requires multiple related views that the stakeholders can interpret from their viewpoint.

Kruchten's 4+1 View model was designed at the outset to describe the architecture of a software–intensive system, using multiple, integrated views. Each view focuses on a different aspect of the software system architecture [37]. As with other architecture frameworks, views, and notations, 4+1 offers a mechanism for engineers and developers to communicate with each other and with stakeholders. Whether someone

speaks the language of DODAF, 4+1, or utilizes any other framework, understanding what are the key elements that comprise a software system and its environment, and where that information is located are critical to dealing with the complexity of a system within a system of systems. The greatest contribution of frameworks like DODAF and 4+1 is that they offer the opportunity to develop a 'common mental model' of the architecture or a model of the architecture of a system.

Rozanski and Woods are optimistic that stakeholders will respond to an architectural description (AD), which they define as "a set of products that documents an architecture in a way its stakeholders can understand and demonstrates that the architecture has met their concerns" [1, p. 25].

Each activity associated with a system's lifecycle may require a different view of the architecture or architecture model to communicate relevant information to different stakeholders with different interests. The interrelated views of the system and environment assist in making a complex, incomprehensible problem into something that is more understandable to all stakeholders.

D. THE ROLE OF FORMAL METHODS, SEMI-FORMAL METHODS AND LIGHTWEIGHT FORMAL METHODS IN ARCHITECTURE MODELING

Architecture models play a significant role in the analysis of a software system, and the degree of formality used to model architecture can range from semi-formal formal, with lightweight formal methods being a practical compromise.

Taylor et al. classify architecture models as informal, semi-formal, and formal. Informal models are typically captured in box-and-arrow diagrams, and can provide an effective high-level view that is understood by many different stakeholders. However, they are inherently ambiguous and often contain only minimal detail. Semi-formal architecture models, such as UML, try to balance precision with enough detail to facilitate communication and support both manual and automated analyses. Formal models are appreciated by technically-oriented stakeholders, and their notations have

formally defined syntax and semantics. Most models used by practitioners are semi-formal [29].

Formal methods introduce mathematical rigor into the design of a software system. Tinelli explains that formal methods have their foundation in “mathematical logic, a discipline that studies the precise formalization of knowledge and reasoning” [38].

Collins describes the role of formal methods in software engineering and computer science, for design and test:

> formal methods are system design techniques that use rigorously specified mathematical models to build software and hardware systems. In contrast to other design systems, formal methods use mathematical proof as a complement to system testing in order to ensure correct behavior. [39]

Jackson discusses that the foundation of software is the abstractions associated with them, where an abstraction is defined as a “structure, pure and simple—an idea reduced to its essential form” [40]. The selection of the correct level of abstraction, in order to address specific questions and concerns, is often easier said than done. Languages such as Z and tools such as Alloy Analyzer assist in the application of formal methods to the world of the practitioner.

There continues to be some debate regarding the practicality of applying formal methods to mainstream software engineering activities. Hall presents a perspective that “formal methods are available and readily useable by practitioners, but yet the theoretical view offered by proponents of these techniques is somewhat overreaching” [41]. Sastry appears to support Hall’s position and suggests that semi-formal techniques must augment formal methods and tools, particularly when addressing system integration [42].

Wieringa describes semi-formal techniques as diagraming and other techniques that use some form of structured natural language [43]. The manual counting technique of FPA lends itself to semi-formal design methods. Collins suggests that because of the rigor involved

> formal methods are always going to be more expensive than traditional approaches to engineering. However, given that software cost estimation is more of an art than a science, it is debatable exactly how much more expensive formal verification is…
>
> While an all-encompassing formal description is attractive from a theoretical perspective, it invariably involved developing an incredibly complex and nuanced description language, which returns to the difficulties of natural language. [39]

Hall also indicates that the term 'formal methods' covers "the use of mathematics in software development" [41]. This includes writing and proving a formal specification, constructing a program based on this specification, and then verifying the program. Hall states that applying formal methods to develop a formal specification provides a "precise definition of what the software is intended to do" [41]. This assists in identifying mistakes prior to implementation in coding.

Wing states that "Formal methods are used to reveal ambiguity, incompleteness, and inconsistency in a system, and expose design flaws early in the development process of the system, before finding them in test" [44].

That having been said, utilizing formal methods in and of itself does not guarantee that the software system will work as intended. Formal methods do assist with removing the ambiguity of natural language associated with an informal specification, and formal specifications do need to be translated back into natural language for discussions with users. That requires a skilled workforce knowledgeable of the application of formal methods, which is minimally available.

Knowing when and where to use lightweight formal methods is critical to achieving return on investment of resources expended applying them. Easterbrook et al., state that "The lightweight approach to formal design recognizes that formal methods are not a panacea: there are areas where formal methods are useful, and areas where a formal specification will accomplish nothing" [45].

Complex, software-intensive system of systems benefit from the discipline and precise descriptions of formal models of the systems, since natural language can be ambiguous. Therefore, a practical alternative to formal design is relevant and needed for

practitioners. A lightweight approach in which formal methods are applied in a limited way, offer the benefits of formal specification without many of the limitations associated with cost and complexity.

As highlighted in Agerholm and Larsen, even with a pragmatic lightweight approach, the "main obstacle is to teach the engineers how to choose which parts to model and how to make appropriate abstractions of these parts" [46].

MP leverages lightweight formal methods and high-level pseudo code, and its supporting information offers examples on how to abstract behaviors. This results in a precise, flexible and practical framework to support behavioral modeling of architectures [3], [32]. MP was selected over other architecture modeling languages for this research based on its ease of use, availability of tools that allowed execution of the architecture model, and views generated by those tools.

E. MONTEREY PHOENIX (MP)

The ThreeMetrics methodology implements Monterey Phoenix, created and described by Auguston, as "a framework for software system architecture and business process (workflow) specification based on behavior models" [33].

The challenge for practitioners is determining how to reduce, rather than automate, complexity. Architectural modeling is a powerful tool, if supported by the appropriate architectural modeling framework and language. Monterey Phoenix renders a view of architectures as high level description of behaviors. This is accomplished at the system and subsystem level and for the interactions between them [32], [33]–[34].

MP utilizes lightweight formal methods to unambiguously describe the behaviors of a system and the environment with which it interacts. The models are written in high-level pseudo code, which gives the model author the ability to be both precise and practical. This research utilized MP architecture models to capture design decisions about precedence, inclusion, and ordering, although the MP language and framework have other capabilities that can be found in [3], [32]–[34], [47]–[51].

Building on the works of Jackson and the Open Management Group, Auguston describes the basic concepts for Monterey Phoenix as follows:

> A view of the architecture as a high level description of possible system behaviors, emphasizing the behavior of subsystems (components) and interactions between subsystems. MP introduces the concept of event as an abstraction of activity.
>
> The separation of the interaction description from the components behavior is an essential MP feature. It provides for a high level of abstraction and supports the reuse of architectural models.
>
> Interactions between activities are modeled using event coordination constructs. The environment's behavior is an integral part of the system architecture model. MP provides a uniform method for modeling behaviors of the software, hardware, business processes, and other parts of the system.
>
> The event grammar models the behavior as a set of events (event trace) with two basic relations, where the PRECEDES relation captures the dependency abstraction, and the IN relation represents the hierarchical relationship. Since the event trace is a set, additional constraints can be specified using set-theoretical operations and predicate logic.
>
> The MP architecture description is amenable to deriving multiple views, and provides a uniform basis for specifying structural and behavioral aspects of a system.
>
> MP supports automated and exhaustive (for a given scope) scenario generation for early system architecture verification. The Small Scope Hypothesis [Jackson 2006] states that most flaws in models could be demonstrated on relatively small counterexamples. [33]

Monterey Phoenix is an expressive language that offers a way to describe the world in terms of interactions: interactions between people, interactions between machines, and interactions between people and machines. The information provided in this section is a basic introduction to the MP event grammar. A more complete description of the language and examples of models can be found in [33] and [50].

Figure 2 is extracted from the MP wiki hosted by NPS and illustrates the structure of an MP event grammar rule. Since MP leverages high-level pseudo code, the MP user has tremendous flexibility in selecting the words to represent behaviors.

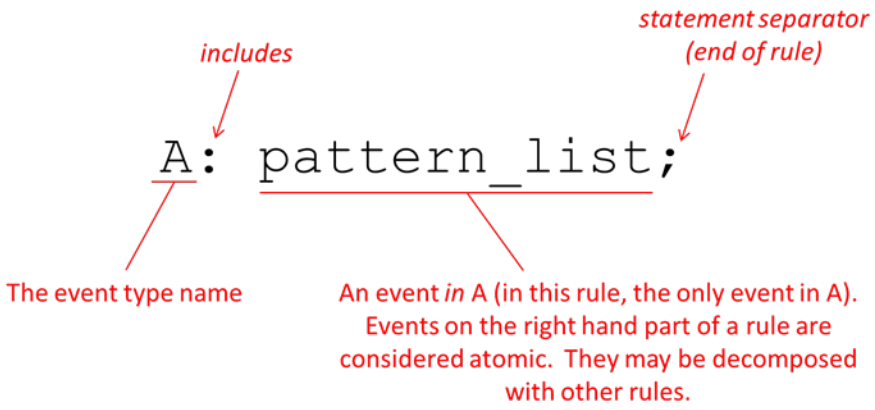

Figure 2. The Anatomy of the Event Grammar Rule. Adapted from [48].

Table 9 is also extracted from the MP wiki and illustrates event patterns, relating natural language descriptions to their expressions as MP event grammar rules [48].

Table 9. Monterey Phoenix Event Patterns. Adapted from [48].

Natural Language Description of Pattern	Pattern Expressed as MP Event Grammar Rule
Unordered set of zero or more events B	A: {* B *};
Unordered set of one or more events B	A: {+ B +};
Unordered set of events B and C (B and C may happen concurrently)	A: {B, C};
Ordered sequence of zero or more events B	A: (* B *);
Ordered sequence of one or more events B	A: (+ B +);
Ordered sequence of events (B followed by C)	A: B C;
Optional event (B or no event at all)	A: [B];
Alternative events (B or C)	A: (B | C);

The MP analyzer on Firebird utilizes the small scope hypothesis introduced by Jackson:

> Most flaws in models can be illustrated by small instances, since they arise from some shape being handled incorrectly, and whether the shape belongs to a large or small instance makes no difference. So if the analysis considers all small instances, most flaws will be revealed… Key idea is specification of a scope, which bounds the sizes of the signatures, and exhaustive search for examples or counterexamples. [40, p. 15]

MP offers the opportunity to refine higher level system behavioral descriptions into more detailed descriptions leading up to implementation in code, while maintaining traceability across the models of the system and environment. This results in more complete behavior descriptions of all relevant components and connectors. As explained by Auguston and Whitcomb, "Event traces can be effectively generated from the event grammar rules and then adjusted and filtered according to the composition operations [COORDINATE and SHARE ALL] in the schema" [32].

MP does not replace system and software engineering enablers such as UML, SySML, and DODAF, but complements them and emphasizes the value of using automated tools for immediate model verification [32]–[34]. As discussed by Object Management Group, the UML definition of a behavior is "a specification of events that may occur dynamically over time" [31].

The representation of a behavior as an event in an executable MP model aligns with the UML definition of a behavior. However, MP is used to not only model the system under analysis, but also the behavior of elements in the environment, using the same framework, which sets the conditions to re-use parts or all of the model. As described by Auguston and Giammarco:

> An event may be considered an abstraction of an activity, and may have duration greater than or equal to zero. System behavior is modeled as a set of events with two basic relations: precedence (PRECEDES) and inclusion (IN). PRECEDES and IN are partial ordering relations. Unordered events may occur concurrently. [48]

Fortunately, tools such Firebird and Eagle6 are available and allow the model author to execute the model and inspect the results using architectural views that can be extracted from the executed MP model. These views help to portray aspects or elements of the architecture that are relevant to the concerns that the view intends to address, and to the stakeholder interested in those concerns. Each view is an answer to a question (or a group of questions), and provides the rationale for the development of tools, patterns, templates, and conventions needed to create the level of abstraction that reduces complexity while retaining meaningful content [3], [32]–[34].

One of the earliest steps in the FP counting process is identifying the application boundary. The ThreeMetrics methodology employing MP assists in unambiguously identifying the boundaries and interactions of the system, user, and environment.

Function Point transactional function types can be thought of as markers of the external boundary. Once the boundary and interactions have been described, the FPA practice can be used to determine the unadjusted FP count.

Use cases, FPA, and behavioral modeling frameworks such as MP can help stakeholders understand the technical and programmatic characteristics of the system and environment, by effectively creating views that contain the information they need. The ThreeMetrics methodology employing MP extracts analysis enablers from the model, such as use cases, and informs programmatic metrics of effort and size estimates.

This research utilizes a subset of the MP tool set focused on ROOTs, COORDINATE, and SHARE ALL. Once MP has been used to unambiguously describe the behaviors of the system under analysis and its interactions with the environment, the resulting MP descriptions of boundaries and interactions (represented by COORDINATE and SHARE ALL in the MP schema) can be related to estimation and costing practices. This will be discussed as part of the ThreeMetrics methodology in Chapter III of this dissertation.

F. ESTIMATES FOR INTEGRATION TESTING

Software testing is a challenging and resource intensive activity. Nowhere is that more visible than during integration testing, when organizations as well as systems have to interact. Sommerville states “software testing involves running an implementation of the software with test data. You examine the outputs of the software and its operational behavior to check that it is performing as required. Testing is a dynamic technique of verification and validation” [10, p. 517].

Verification and validation are not synonymous terms, but they are symbiotic and can effectively communicate the status and relevance of a system through its architecture model. Boehm very simply but powerfully synopsized the difference “Am I building the product right? Validation: “Am I building the right product?” [52].

Once individual component testing is complete, the next step is to integrate the components into a system, and then assess whether or not the system behaves as expected. The value of integration testing is its focus on information flowing across interfaces to modules. The challenge is writing integration test cases that can confirm that the observed behavior is the expected behavior. Pfleeger and Atlee note “the integration is planned and coordinated so that when a failure occurs, we have some idea of what caused it. In addition, the order in which components are tested affects our choices of test cases and tools” [23, p. 390].

Many practitioners experience the challenge of testing within the schedule and resource constraints of their organization. Testing is often not allocated the appropriate amount of time for thorough investigation. Brooks provides “the following rule of thumb for scheduling a software task: 1/3 planning, 1/6 coding, 1/4 component test and early system test, 1/4 system test, all components in hand” [53, p. 20].

MP models generate all event traces within the given limit, and the resulting event traces can be inspected to help developers identify undesired behaviors, and as blueprints to create test cases. TutorialsPoint synopsizes the definition of a software test case: “A test case is a document, which has a set of test data, preconditions, expected results and

post conditions, developed for a particular test scenario in order to verify compliance against a specific requirement" [54].

Additionally, a test case includes test steps, test data that supports what the test case needs to achieve, expected results, and information about the environment. Once the test case is executed, time is needed to analyze the results. An integration test case addresses the interface and data flow between modules or systems, focusing on what happens at the boundary.

The creation of integration test cases takes effort. The event traces generated from an MP model provide solid detailed blueprints, which can be viewed as guidelines for the creation of the integration test cases, and inform technical and programmatic decision making.

The MP Analyzer on Firebird is an implementation of the MP event trace generator, which utilizes the small scope hypothesis. The event traces are contained by simulating a limited number of iterations, usually three or less [32].

Auguston and Whitcomb leveraging Jackson discuss MP as an executable architecture model and state:

> It is possible to obtain all valid event traces within a certain limit. Usually such a limit (scope) may be set by the maximum total number of events within the trace, or by the upper limit on the number of iterations in grammar rules (recursion in the grammar rules can be limited in similar ways). For many purposes a modest limit of a maximum 3 iterations will be sufficient. This process of generating and inspecting event traces for the schema is similar to the traditional software testing process. [32]

A generic description of all behaviors (the MP schema) is more difficult to evaluate than an example of behavior (a particular event trace). Tools such as Firebird assist in these evaluations by generating an exhaustive set event traces, usually for a scope of one, that can then be inspected to and used to inform integration test cases.

In the COCOMO II output, integration and test costs are part of the phase effort for construction. In this phase, breakdown of the total construction is 76% of the software development effort. Using the waterfall lifecycle definitions for COCOMO II the

breakdown is as follows: Product Design 17%; Programming 58%; Integration and Test 25% [55]. Once the UFP count is input into COCOMO II, 25% of the resulting Construction phase output for schedule is used in the for this calculation. The work week is assumed to be five days per week and eight hours per day for each staff person. Assuming that six test cases per day can be executed, the number of test cases can be executed in the allocated time for test and integration, is calculated. This does provide information for next steps to inform decision making, both technically and programmatically. The first step is to revisit the model and ensure that the behaviors of the application are accurately captured. If the model is correct, then the next step is to determine if there is any flexibility in the schedule and resources to support additional testing. If the number of test cases is unrealistic, it becomes clear that only a subset of event traces can be selected for testing.

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III. METHODOLOGY

The ThreeMetrics methodology applies elements of the function point counting methodology to MP architecture models, to extract an unadjusted function point count from MP models. It then uses the unadjusted FP count to calculate estimated effort thru the COCOMO II cost methodologies. The MP model itself is a rich source of information and can be used to extract event traces that inform integration test case development, as well as views of instances of the architecture model that can be inspected for accuracy, and facilitate communication with stakeholders. MP models are executable, taking advantage of available automated tools, such as Firebird, which was used for this research. The overall methodology illustrated in Figure 3 is synopsized in the following steps, each of which is then discussed in more detail.

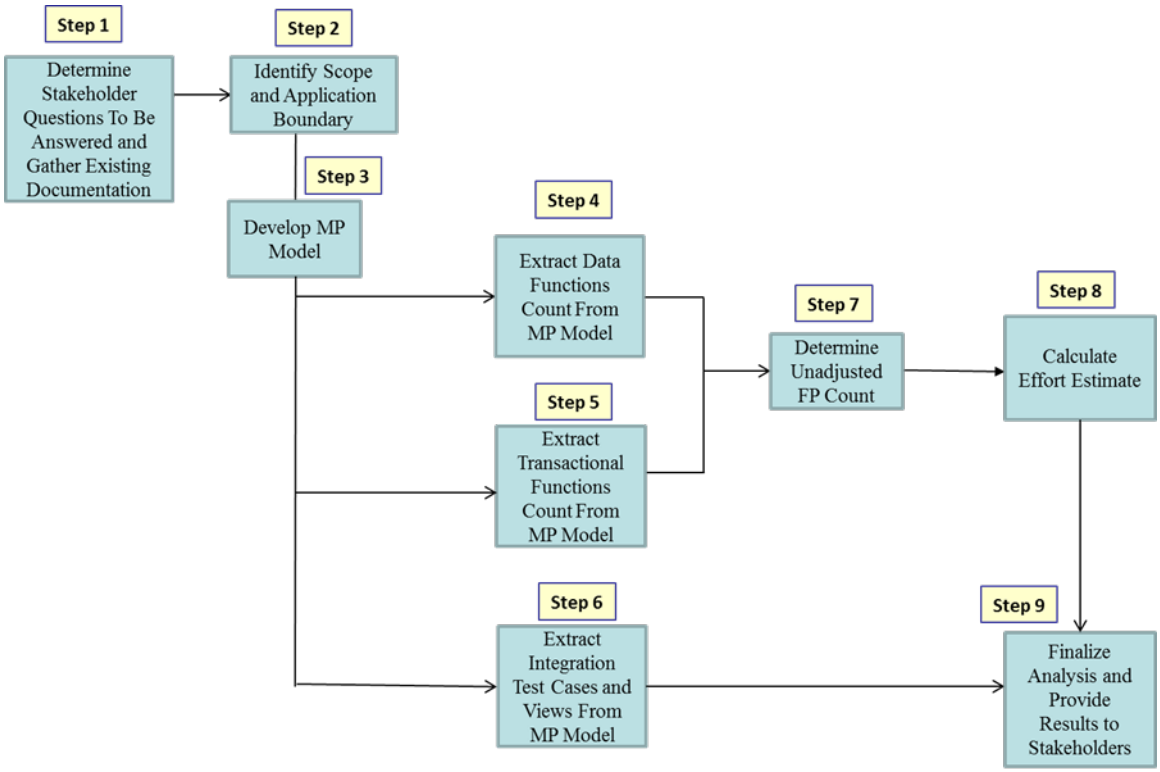


Figure 3. The ThreeMetrics Methodology Overview

Step 1: Determine stakeholder questions to be answered and gather existing documentation

Step 2: Identify scope and application boundary

Step 3: Develop MP model

Step 4: Extract Data Functions count from MP model

Step 5: Extract Transactional Functions count from MP model

Step 6: Extract integration test cases and views from MP model

Step 7: Determine the Unadjusted Function Point (UFP) count

Step 8: Calculate effort estimate

Step 9: Finalize analysis and provide results to stakeholders

(1) Step 1: Determine stakeholder questions to be answered and gather existing documentation

The first step of this methodology is to understand why the model is being developed and what existing documentation is available to assist in understanding the software system and the environment (everything but the system) with which it interacts. Questions or groups of questions related to a software system exist for a spectrum of stakeholders, as discussed in Chapter II Section C of this document. In order to address these questions, the first step is to gather all available source information supporting what the user expects the system to do.

Practitioners of the FP counting methodology recommend using any documentation or architectural artifacts that may be available when performing a functional size measurement, such as requirements documents, entity relationship diagrams, interface agreements with descriptions of interfaces to/from other applications, or any other supporting documentation that provides insights into what the application is intended to do [9], [14]–[16].

This approach is consistent with software and system engineering analyses. An additional artifact that assists in defining the software system under assessment is the information assurance documentation that defines the accreditation boundary of the system, from which more detailed information of software components can be recovered.

One way to capture the expectations of the users is by examining and refining functional requirements. Leveraging techniques from FP counting, functional requirements are assessed in order to shape what the application is intended to do, from the perspective of the user. The user of the application can be a human or another machine. This translation of often ambiguous natural language requirements and supporting artifacts into more precise FP counting representations is the most challenging part of Step 1. Recall, the FP terms transactional functions, data functions, and functional complexity determined by the number of DETs, FTRs, and RETs from Chapter II Section B of this document. Using a combination of information from multiple FP counting manuals, and leveraging the support documentation, the next sequence in Step 1 is to begin to decompose ambiguous natural language of the functional requirements into precise activities that can be related to FP transactional, data functions, and assist in confirming the boundary of the application. This is the most challenging part of the methodology.

(2) Step 2: Identify scope and application boundary

The information gathered in Step 1 assists with understanding what the application is intended to do at a high level, from the perspective of the user. Step 2 utilizes this information to determine the scope of the count from the FP counting methodology perspective, i.e. is it a Development Project FP count, an Enhancement Project FP count, or an Application FP count. Most importantly, Step 2 utilizes this information to identify the boundary of the application to be counted, a critical step in any software or system engineering analysis when trying to distinguish the system under analysis and the environment with which it interacts.

As discussed Chapter II Section B, understanding the type of project and FP count from an FPA perspective assists in understanding which application is maintaining the

data and confirming the boundary of the software system or component of the system to be counted.

The supporting documentation of different software systems has various artifacts to describe the systems, but these artifacts are often not consistent and may be incomplete. However, at a minimum, a simple box and arrow type of architectural representation can usually be recovered. Since the natural language of the functional requirements may still be ambiguous, a quick inspection of the box and arrow representation can be performed to confirm that the boundary of the application to be counted is correct and clearly visible, that all currently known data functions are present, and all currently known transactional functions are present. It also supports the decomposition of the application to be counted into the ILFs and an Internal Abstracted Application (IAA), which represents everything except the ILFs. The use of an IAA was to represent behaviors between the ILFs, EIFs and IAA in order to account for the UFP count for data functions, and will be discussed in Step 3.

Figure 4 illustrates the ThreeMetrics box and arrow simplified view. The red dotted line represents the boundary. While this is high level architecture view does not adequately represent the software system behaviors needed to extract the UFP count, it is a practitioner's tool to set the conditions to develop an MP model that does represent the behaviors of the data functions, the behavior of the internal abstracted application, and the behavior of the user in more detail. This view resonates with non-technical stakeholders, who provide the go/no-go to proceed with additional analyses.

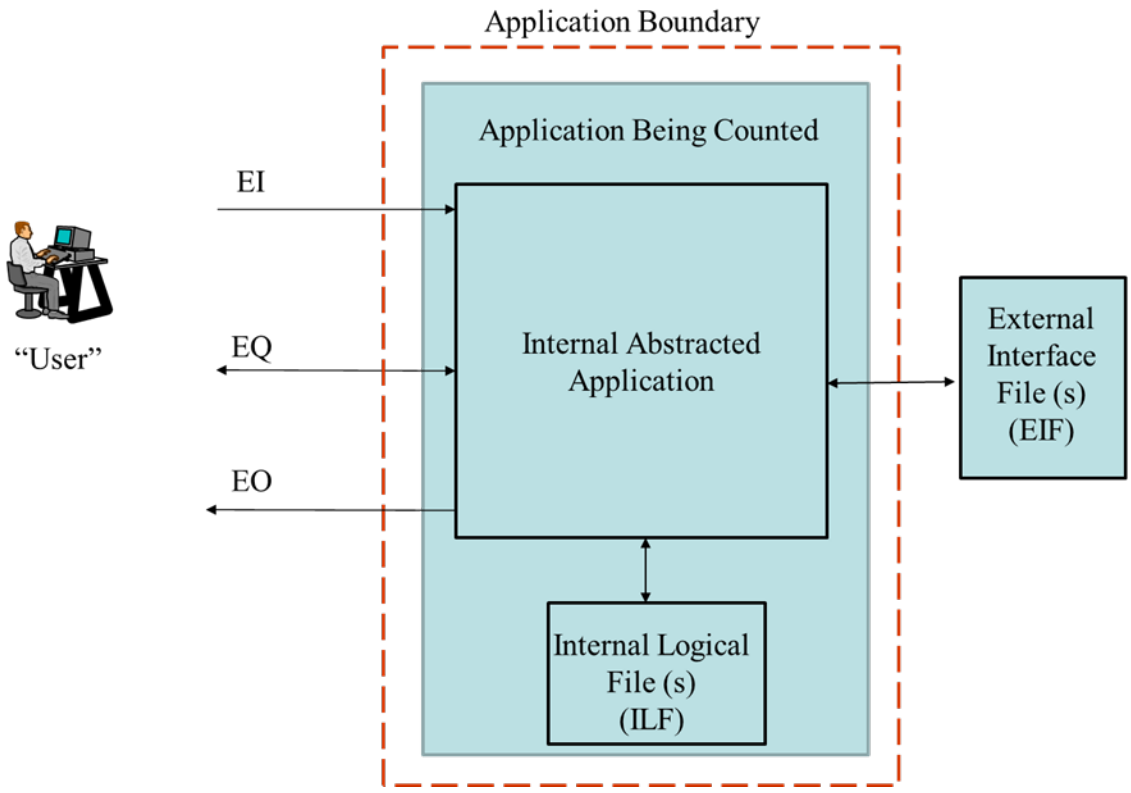


Figure 4. ThreeMetrics Box and Arrow Simplified View

The next activity in this step is to further refine the behaviors of the application, based on the documentation gathered in Step 1. By far the most difficult part of this activity is fully understanding the behaviors of the software system, to determine the DET counts, ensure that the RETs within an FTR are appropriately identified, and ensure that the transactional functions (EI, EO, EQ) are also identified. Although more detailed examples demonstrating this methodology will be provided later on in this document, for the purposes of explaining the methodology, a short example will accompany the next several steps.

When identifying candidate EIs, EQs, and EOs, it is critical to establish a convention to keep track of all the information. As illustrated in Figure 5, adapted from [56], one approach is to capture the name of the transactional function, the FTR associated with it, and the DETs counted for that transaction. Consider the EQ named State Drop Down, outlined by a blue dotted line. Associated with this EQ is the number

of FTRs (1) and the number of DETs (2), and the identification of the FTR, in this case Golf Courses ILF. For this EQ, the information is synopsized as EQ: State Drop Down, (1,2), Golf Courses.

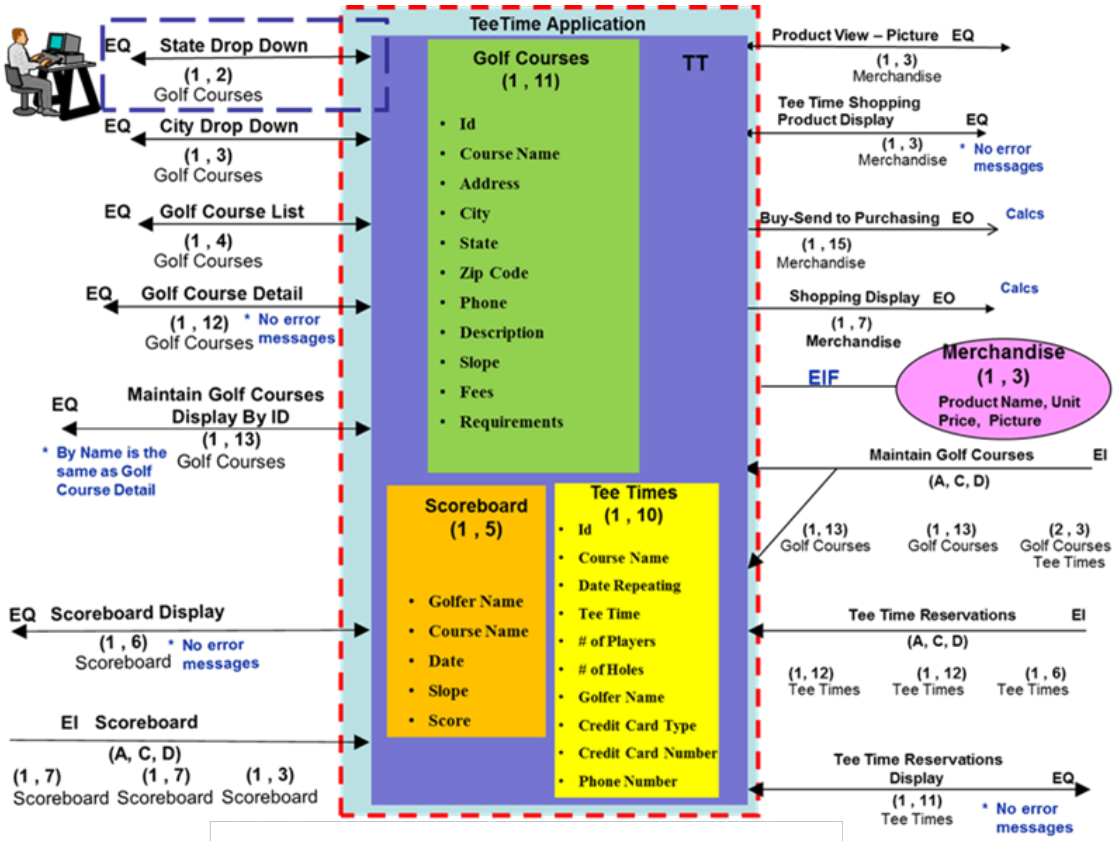


Figure 5. Tee Time Generic Box and Arrow View. Adapted from [56].

This EQ was identified from the source information associated with the Tee Time application, which is described in more detail in Chapter IV. A representative screen for the application, Golf Courses List, is illustrated in Figure 6. On this screen and from the narrative accompanying the screen in the source information, the State Dropdown EQ was identified, and the behaviors associated with this transactional function were also identified, and counted as DETs.

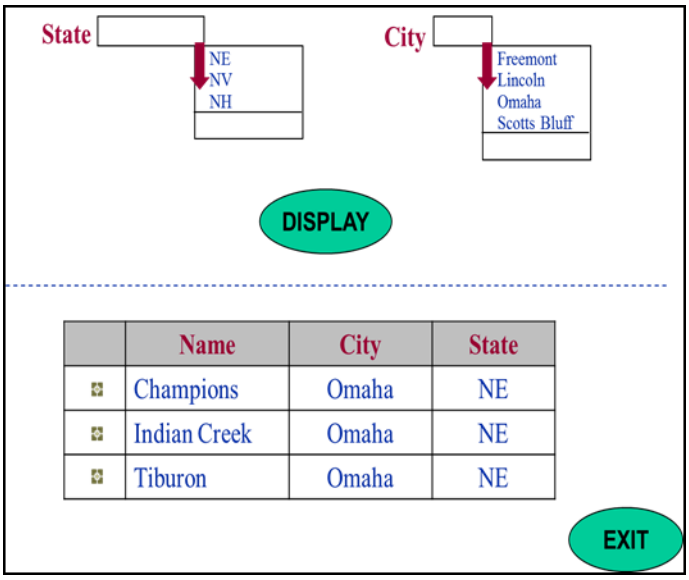


Figure 6. Golf Courses List Screen. Adapted from [56].

For EQ: State Drop Down, the behaviors include: (1) Click on state arrow, (2) State list display returned. There is one FTR (Golf Courses ILF), and 2 DETs (Arrow Click, State field) identified. Therefore, the user is interacting with the application, querying for information that is resident in the Golf Course ILF. The information is then displayed back to the user, on the screen. This process is continued until all transactional functions are clearly identified.

Similarly, for data functions, the Record Element Type associated with an ILF or EIF is elicited from the supporting documentation gathered in Step 1. Each ILF and EIF is assigned a name, and the data elements associated with each are delineated and counted. Any logical groupings of data from the user's perspective, internal to the EIF or ILF, is documented as an RET. In this example, there is one RET and 11 DETs represented in Figure 5 as Golf Courses ILF (1, 11).

In a manual unadjusted FP count, the next step would be to determine the functional complexity based on functional complexity tables provided by the IFPUG counting manual [9], such as Table 4 for an EQ.

To keep track of all this information, Table 10 provides a synopsis of the elementary process (EP), in this case an EQ, described as State Drop Down, which

references the Golf Course ILF (I). There is 1 FTR and 2 DETS, represented as (1, 2). Therefore, the complexity (Complex) is considered Low, and that corresponds to 3 UFPs for this EQ.

Table 10. UFP Count for EQ State Drop Down

EP	Description	ILF/EIF	FTR/DET	Complex	UFP
EQ	State Drop Down	Golf Courses (I)	(1,2)	Low	3

(3) Step 3: Develop MP Model

Once the application boundary is drawn (see the red dotted line) and candidate transactional and data functions are identified, the conditions are set to enrich the box and arrow representation with high level behavioral descriptions of the software system being counted, derived from the source information in Step 1. Figure 5, while helpful, soon becomes unwieldy, containing so much information that it defeats its original purpose of simplification. Although this view is an initial representation of the behaviors of the software system, representing the model in MP was much more efficient.

MP events can be represented in pseudocode, using formalisms to refine the event descriptions. MP events include interactions between actors (e.g., ROOT User, ROOT ILF). UFPs represent interaction abstractions and can be extracted from COORDINATE and SHARE ALL MP constructs. The descriptions of interactions can be captured in a high level MP COORDINATE that effectively says “do something, and then something else happens” in pseudocode. Hidden within the high level COORDINATE are all the other interactions that are represented in FPA by DETs and FTRs, referenced to assess a complexity. The structure of events visible in an MP model provides the source for assigning weights. The nested COORDINATE will have composite events, and the number of composite events will affect the weight. The weights can be derived from the complexity of interactions and FPA functional complexity rating. These calculations can

be done by automated tools that relate the MP model to COCOMO calculations, such as http://csse.usc.edu/tools/MP_COCOMO [57].

Recall, the MP terminology from Chapter II Section E. User, ILFs, EIFs, and an IAA in Figure 4 are identified as ROOTs. The ILFs, EIFs and User each interact with the Internal Abstracted Application ROOT, but do so in slightly different ways. The interaction of the ROOTs is represented by composition operations COORDINATE and SHARE ALL.

The use of an IAA was to represent behaviors between the ILFs, EIFs and IAA to account for the UFP count for data functions. Had the interactions been between the user and the ILFs and EIFs, these interactions would have accounted for the contributions of the transactional functions to the UFP count, but not those of the data functions. SHARE ALL was chosen to represent interactions between the IAA and ROOTs for data function types. It should be noted that if enough information were available on the data functions, then nested COORDINATE could be also used to represent the interactions between the ILF or EIF and the IAA.

COORDINATE was chosen to represent the high level interactions (EI, EO, EQ) of the transactional functions, and then nested interactions (nested COORDINATE) to represent the DETs that determine the functional complexity rating. This functional complexity rating corresponds to an UFP count in the IFPUG tables, and was used as multiplied with the COORDINATE, resulting in the same UFP count as a manual UFP count for that transactional function. The initial UFP count extracted from the MP model and the manual UFP count are very close, if not identical. However, the MP executable model is amenable to stepwise refinement, and the count of COORDINATEs and SHARE ALLs can be extracted from the model using manual inspection and automated tools. This will be discussed in more detail in Step 7.

Continuing with the EQ State Drop Down transactional function type, the MP schema for this transactional function type and the nested operations associated with DETs is described in Figure 7.

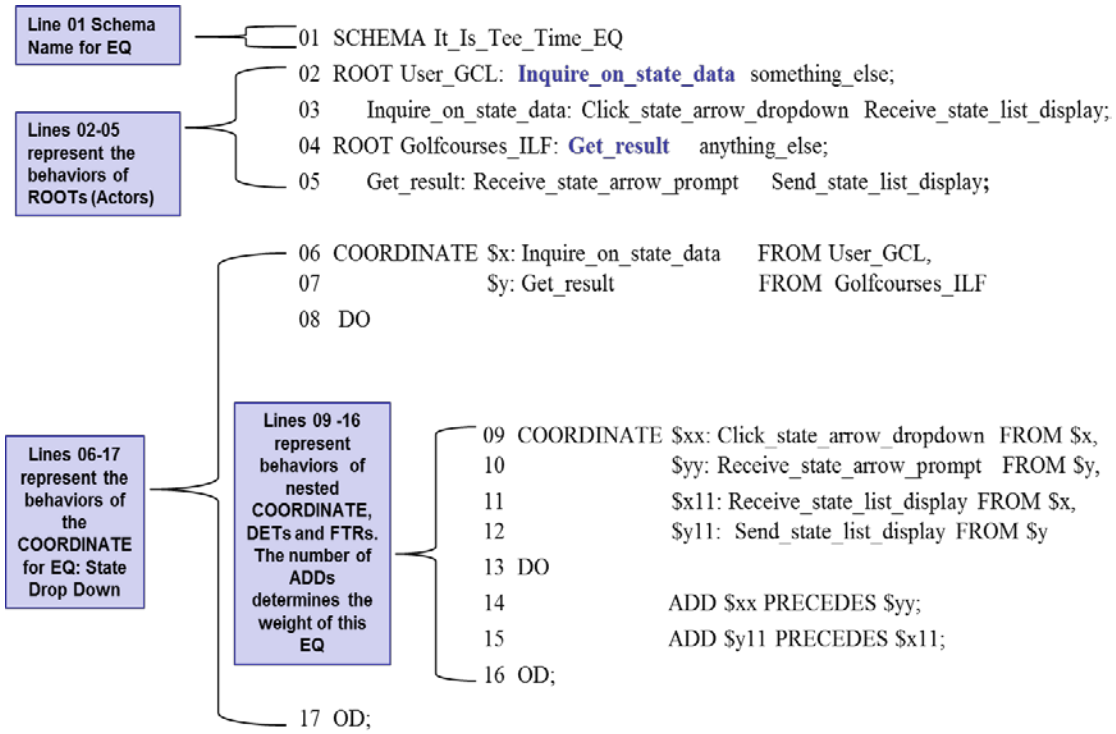


Figure 7. MP Schema Description for EQ State Drop Down Example

The naming convention of the ROOTs is to assist with managing the complexity of the descriptions of ROOT behaviors and the interactions between the ROOTs. For example, the user interacts with the TT Internal Abstracted Application, to inquire on data that is in the Golf Courses ILF. ROOT TT_GC_ILF represents the abstracted combination of the Golf Courses ILF and the TT Internal Abstracted Application (referred to hereafter as TT), both of which are internal to the Tee Time application boundary.

(4) Step 4: Extract Data Functions count from MP model

The behaviors of an ILF or EIF data function can be represented as interactions with the internal abstracted application using nested COORDINATE if sufficient information is available, or SHARE ALL if information is incomplete or sparse.

COORDINATE requires two events and SHARE ALL requires a single shared event. SHARE ALL is the simplified form of interaction, when who initiates the interaction and who is the recipient is not relevant. The MP representation of data function type interaction is illustrated in Figure 8 for SHARE ALL.

```
SCHEMA Data Function
ROOT TT: (* ( writing | reading ) *);
ROOT GC_ILF:  (+ writing +) (* sending *);
TT, GC_ILF SHARE ALL writing;
```

Figure 8. MP Schema For Data Function: SHARE ALL

A similar representation using COORDINATE is illustrated and in Figure 9.

```
SCHEMA Data Function
ROOT TT: (* ( start_writing | reading ) *);
ROOT GC_ILF:  (+ finish_writing +) (* sending *);
              COORDINATE  $a: start_writng    FROM TT,
                          $b: finish_writing FROM  GC_ILF
              DO          ADD $a PRECEDES $b; OD;
```

Figure 9. MP Schema For Data Function: COORDINATE

The MP schemas illustrated in Figures 8 and 9 can be manually inspected. There is one SHARE ALL in Figure 8 and one COORDINATE in Figure 9. The COORDINATE or the SHARE ALL corresponds to one data function type, in this case Golf Courses ILF. Once the number of COORDINATEs or SHARE ALLs are extracted

from the schema, the IFPUG tables are used to determine the functional complexity rating and corresponding UFP size.

(5) Step 5: Extract Transactional Function Count from MP model

Each EI, EQ, or EO transactional function is represented in the MP model by a COORDINATE composition operation. The number of interactions nested within the COORDINATE are directly related to the functional complexity and size values in the IFPUG tables.

For example, if an EQ = 1 COORDINATE, then the next step is to inspect the number of interactions within that COORDINATE. If the number of interactions between one IAA (ILF/EIF) ROOT combination and the User is 15 or less, this corresponds to a functional complexity of Low.

Multiplying the EQ by the functional size value (in this case 3 for Low) will equal the number of UFPs for that EQ. This requires a specific understanding between the parent COORDINATE and the nested interactions representing the DETs. Otherwise, a generic approach is to arbitrarily assign a functional complexity value of average to the transactional functions, until a more refined understanding of the behaviors can be made.

(6) Step 6: Extract Integration Test Cases and Views from MP Model

MP provides a rich source of information that informs effort. The UFP count extracted from an MP model will be discussed in Step 7.

All executable architecture models, including MP, must be inspected, tested, and debugged before users can extract information from them. Once the model is considered correct, then there is a greater degree of confidence that all scenarios and use cases generated by the model are also correct. Each scenario or use case can then inform a test case, to support implementation.

MP can be used to automatically produce event traces, which represent examples of behaviors (e.g., scenarios, use cases if the environment is included). Recall that an event trace represents an example of a particular execution of the system extracted from the architecture that is specified by an MP schema. In the case of executable MP models,

all event traces within a given limit can be generated. Auguston states that “usually such a limit (scope) is set as the upper limit on the number of iterations in grammar rules” [33].

For some MP models, Scope 1 is sufficient because increasing the scope will result in a large number of event traces that may not show anything new or notable, and will not improve chances of exposing errors in testing. The executable model may take too long to run, resulting in a poor return on investment of time and effort. Auguston and Whitcomb leverage Jackson’s work on the small scope hypothesis and observe

> in the case of MP models it is possible to automatically generate all event traces within the given scope (exhaustive testing). Careful inspection of generated traces (scenarios/use cases) may help developers identify undesired behaviors. Usually it is easier to evaluate an example of behavior (particular event trace) than the generic description of all behaviors (the schema). The Small Scope Hypothesis states that most errors can be demonstrated on relatively small counterexamples. [3]

An MP schema describes all behaviors generically, whereas as an instance of a behavior is represented in an event trace. Tools such as Firebird assist in the evaluation of behaviors by generating an exhaustive set of event traces for a scope. The event traces can individually inspected to determine which ones may be best suited to serve as a blueprint for integration test case generation.

As an example, the MP schema for EQ State_drop_down was executed using Firebird, with an event trace illustrated in Figure 10 that was extracted from the model. This is one transactional function from the It’s Tee Time [56] example, which will be discussed in Chapter IV.

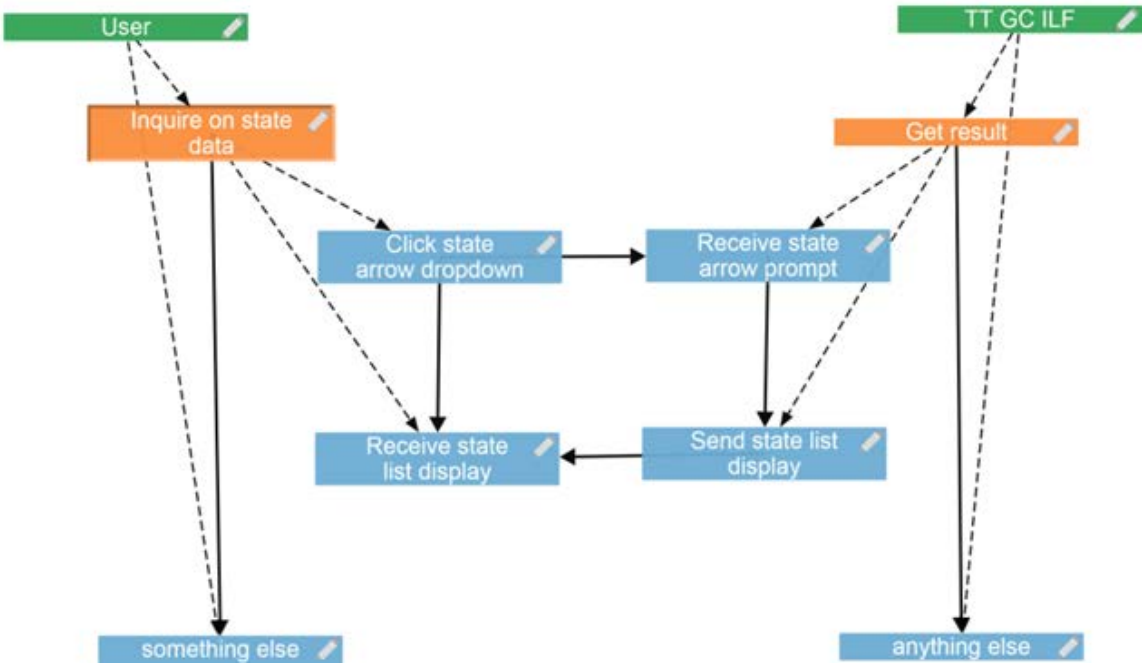


Figure 10. MP Event Trace

The event trace in Figure 10 illustrates the behaviors of User and TT_GF_ILF and the interactions between them, which can be used to identify the steps in a test case. For this event trace, the user's input results in two events: The user clicks the arrow for state drop down (Click_state_arrow_dropdown); and the user should receive state list display (Receive_state_list_display). Receive state list display is a description of the expected system's output.

Brooks observed that 25% of total effort is dedicated to integration testing [53]. Wolff indicates that approximately six integration tests per day can be executed for a large application, such as an electronic commerce system [58]. This does not include the amount of time required to create or analyze the test case.

The amount of time for integration test case construction varies by the complexity of the interface being tested and the identification of test data. The time to create integration test cases ranges from several hours for a simple test case to several days for a more complicated one. Estimates are not only numbers; they provide useful information for informed decision making regarding the planning, implementation overall, and

management of a real software project. If 500 integration test cases are needed to ensure all behaviors of a system are covered, but an organization is resource-constrained or schedule-constrained and can only execute 50 integration test cases, which integration test cases should be selected? The process and criteria for selecting a subset of test cases is a topic for future work.

(7) Step 7: Determine the Unadjusted Function Point (UFP) Count

When specificity related to the application is unclear, one approach is to initially assign an average functional complexity rating to all transactional and data function types. Another approach is to consider how transactional and data function type complexity are rated in similar applications and assign that complexity to the application of interest. When there is clear information associated with the application, the functional complexity and size tables can be applied directly. The total UFP is the sum of the transactional function type UFP count and the data function type UFP count.

Total UFP = Total Data Function Type UFP Count + Total Transactional Function Type UFP Count

Continuing with the Tee Time example and focusing on the Golf Courses ILF (GC_ILF), on SHARE ALL is identified through manual inspection of the MP schema in Figure 8. From the source information that will be discussed in the complete example in Chapter IV, there is one RET and 1–19 DETs associated with this ILF, so that the functional complexity is Low, as illustrated in IFPUG Table 11.

Table 11. Functional Size for Data Functions. Adapted from [9, Sec. 1, p. 13, Table 2].

	1 to 19 DETs	20 to 50 DETs	51 or more DETs
1 RET	Low	Low	Average
2 to 5 RETs	Low	Average	High
6 or more RETs	Average	High	High

Table 12 illustrates that a functional complexity of Low for an ILF corresponds to a functional size of 7 UFP in a manual count.

Table 12. Functional Complexity For ILF and EIF. Adapted from [9, Sec. 1 p. 13 Table 1].

ILF Translation Table: Use the following table to assign a functional size to each ILF.

Functional Complexity Rating	Function Points
Low	7
Average	10
High	15

ILF

EIF Translation Table: Use the following table to assign a functional size to each EIF.

Functional Complexity Rating	Function Points
Low	5
Average	7
High	10

EIF

Using that size, multiply the SHARE ALL by the # UFP/SHARE ALL, where the # UFP/SHARE ALL is obtained from the functional size, in this case 7.

Golf Courses ILF = (1 SHARE ALL) * 7 UFP/COORDINATE = 7 UFPs

The same approach can be applied for the MP schema in Figure 9. Inspecting this schema shows that there is there is one COORDINATE. Based on the source information in Chapter IV, there is one RET and 1–19 DETs associated with GC_ILF, so that the functional complexity is low and from Table 11, and the functional size is 7 UFP from Table 12.

Golf Courses ILF = (1 COORDINATE) * 7 UFP/COORDINATE = 7 UFPs

The data functions pose an interesting challenge. If minimal information is available regarding the ILF or EIF, one approach to estimating the size is to assume an

average functional complexity and associated functional size for an ILF and EIF (10 and 7 UFP, respectively) from Table 11 and 12. This is applicable whether using SHARE ALL or COORDINATE. However, if the source information associated with an ILF or EIF is sufficient to describe the number of RETs and the number of DETs, a nested COORDINATE can be used for those data functions adequately described. Otherwise, defaulting to SHARE ALL with an average functional complexity and size until more information is available is the preferred starting point. The full It's TeeTime example in Chapter IV includes sufficient information to represent data function behavior using the nested COORDINATE composition operation.

The UFP for transactional function types, such as the EQ: State Drop Down, also begin by manual inspection of the MP schema. In Figure 9, there is one COORDINATE, and nested within the COORDINATE are two ADDs. The COORDINATE corresponds to one transactional function, in this case an EQ. Each of the ADDs corresponds to a DET. From the source information and its representation in Figure 5, there is one FTR, Golf Courses ILF. Once the number of COORDINATEs and DETs are extracted from the schema, the IFPUG tables can be used to identify functional complexity and size for this transactional function.

As illustrated in Table 13, 0–1 FTRs and 1–5 DETs correspond to a functional complexity rating of Low for this EQ. A Low functional complexity rating corresponds to a functional size of 3 UFP. The EQ COORDINATE is then multiplied by the # UFP/COORDINATE, where the # UFP/COORDINATE is obtained from the functional size for each transactional function, in this case an EQ.

Table 13. Functional Complexity and Size for EQs. Adapted from [9, Sec.1, p. 19, Table 7 and Table 8].

External Inquiries: EQ

	1 to 5 DETs	6 to 19 DETs	20 or more DETs
0 to 1 FTRs	Low	Low	Average
2 to 3 FTRs	Low	Average	High
4 or more FTRs	Average	High	High

External Inquiries: EQ

Functional Complexity Rating	Function Points
Low	3
Average	4
High	6

EQ State Drop Down = (1 COORDINATE) * 3 UFP/COORDINATE = 3 UFPs

For an EI, EQ, or EO represented by a COORDINATE, once the number of interactions nested within the COORDINATE (one ADD for each DET) is determined, it can be related to the functional size.

Recall, the IFPUG counting tables for functional complexity and functional size, illustrated in Table 13.

One approach to relate the data functions to the MP architecture's model language would be to use SHARE ALL for interactions between the internal component of the application being measured and the External Interface Files and the Internal Logical Files.

As discussed earlier, when insufficient information is known about the application to be measured, an initial UFP count can be obtained by assuming an 'average' functional complexity for transactional and data functions. The functional complexity and functional size values for average are not the same for EI, EO, EQ, ILF and EIF. If each is represented by a COORDINATE or SHARE ALL, one approach would be to average the EO, EI, and EQ complexity and sizing values from the IFPUG tables and use them for each COORDINATE associated with an EI, EO, EQ, and for each SHARE ALL associated with an ILF or EIF. For the functional size of a data function (i.e., ILF or EIF) consider:

Average = 8.5 i.e., (10+7)/2

Use the average functional size value of 8.5 for any data function interaction captured by SHARE ALL.

The same can be said for the transactional functions, where EI and EQ have the same value and EO differs:

Average = 4.5 i.e., (4 +5+4)/3

Use the average functional size value of 4.5 for every transactional function described by a COORDINATE.

(8) Step 8: Calculate Effort Estimate

As discussed in Chapter II Section A of this dissertation, COCOMO II can utilize UFP counts or software lines of code as an input to estimate effort. UFP counts can be transformed into lines of code based on the software implementation language used. This can be done manually leveraging the equations in [4] and [5], or by using the COCOMO II automated tool [57]. The implementation in [57] has been extended by Madachy and Auguston to not only accept an UFP direct input, but also an MP file from which the UFP count is extracted.

Figures 11 and 12 illustrate the options available for the MP-COCOMO II extended implementation, where an UFP can be manually inserted into the model or a MP .mp file can be uploaded. There are many options available as inputs to the COCOMO II model. The options used for this research are discussed in this section. A more complete description of the input options can be found in [4].

For Software Size Sizing Method, the FP selection represents leads to the unadjusted function point input. Software sizing options include Sizing Method and Input Method. The sizing method can be either FPs or SLOCs. Input Method can be Direct or File Input.

If Input Method selected is Direct, then the number of UFPs are inserted in the corresponding field. A language is then selected from options including Basic, C, Database-default, JAVA, PERL, 3rd Generation Language. JAVA was selected for this research.

If Input Method selected is File Input, then the option of Select Input File is offered and an MP schema file with extension .mp can be uploaded.

Once the UFP are inserted and a language option is selected, then the other inputs to the model can be selected. For this research Nominal was selected for all options, Maintenance selected was off, and a software labor rate of $20,000 was used.

Consider the following example for a Direct input of 75 UFPs extracted from an MP schema. Options selected are intended to result in a nominal level of effort.

Additionally, Maintenance is off, and software labor rate is assumed to be $20, 000. The resulting estimate is illustrated in Table 14 Nominal Option Estimates.

Table 14. Nominal Option Estimates

Option	Effort	Schedule	Cost	Language	Total Equivalent Size
Nominal Effort Options Selected, Maintenance Off	13.4 Person-months	8.6 months	$268,205	Java	3975 SLOC

Figure 11 illustrates all of the nominal options selected and Maintenance off, for a direct input of 75 UFPs using the JAVA implementation language.

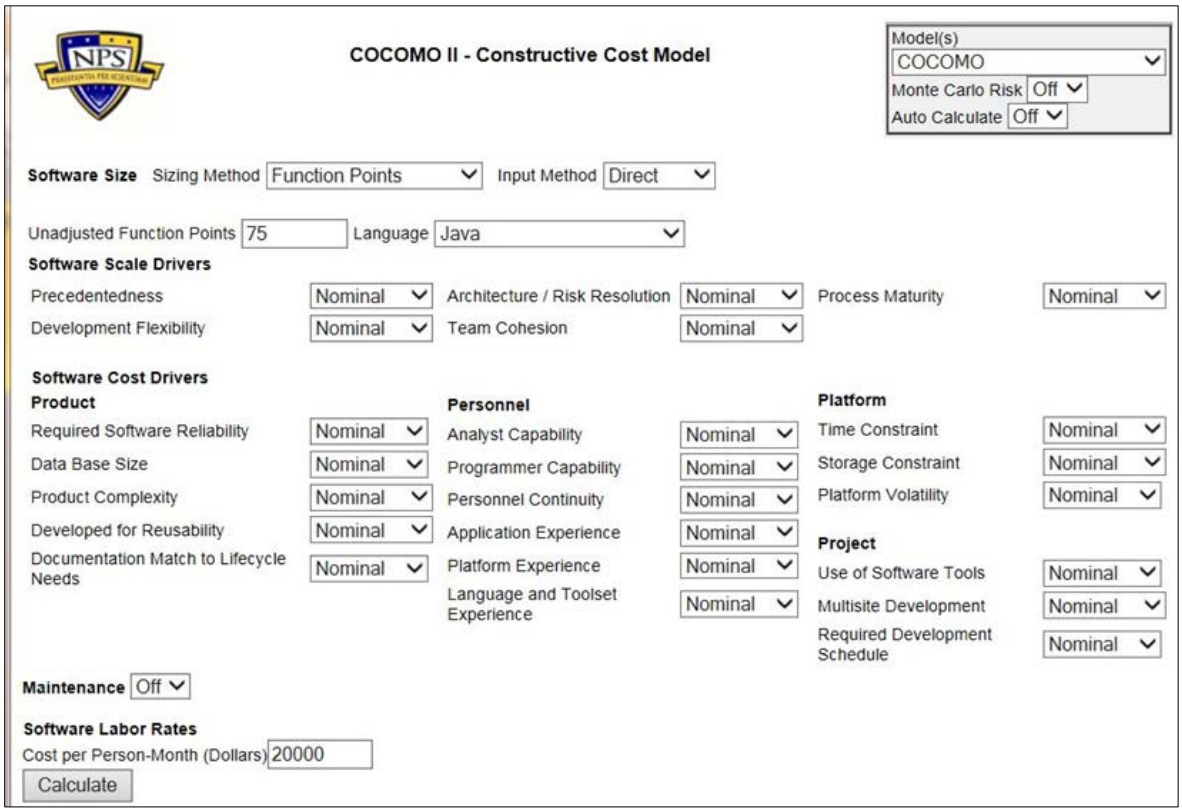


Figure 11. Nominal Effort Options Selected, Maintenance Off

The results are captured in Figure 12, where Effort is 13.4 Person-months, Schedule is 8.6 months, Cost is $268,205, and Total Equivalent Size is 3975 SLOC.

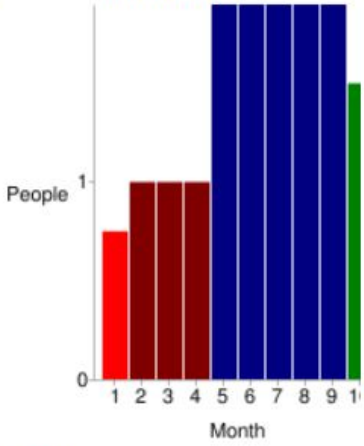
Results

Software Development (Elaboration and Construction)

Effort = 13.4 Person-months
Schedule = 8.6 Months
Cost = $268205

Total Equivalent Size = 3975 SLOC

Staffing Profile



Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	0.8	1.1	0.7	$16092
Elaboration	3.2	3.2	1.0	$64369
Construction	10.2	5.4	1.9	$203837
Transition	1.6	1.1	1.5	$32185

Software Effort Distribution for RUP/MBASE (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	0.1	0.4	1.0	0.2
Environment/CM	0.1	0.3	0.5	0.1
Requirements	0.3	0.6	0.8	0.1
Design	0.2	1.2	1.6	0.1
Implementation	0.1	0.4	3.5	0.3
Assessment	0.1	0.3	2.4	0.4
Deployment	0.0	0.1	0.3	0.5

Your output file is http://csse.usc.edu/tools/MP_COCOMO/data/COCOMO_June_26_2016_18_36_30_39376.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

Figure 12. Nominal Options Selected, Maintenance Off, Results

Recall that the SLOC can be calculated manually from an UFP count for a given software language. For this example, using the values in Table 2 for JAVA, (75 UFPs * 53 SLOC/UFP) = 3975 SLOC. This is the same number from the COCOMO II model results in Figure 12.

(9) Step 9: Finalize Analysis and Provide Results to Stakeholders

As illustrated in Table 11, for every stakeholder, there is at least one distinct way of representing the answers to his or her question. Each stakeholder is interested in a slightly different representation of the same information, and each representation must accurately represent a segment of the whole set of information. Some of this information can be represented in well-known architecture views such as box and arrow diagrams, activity diagrams, or sequence diagrams. Other information can be represented as high-level pseudo code or ranges of cost estimates. What is important is the accuracy and traceability of the information in each representation and its ability to communicate with a stakeholder.

One of the criticisms of UML is that its views can be created independently of each other, with no guarantee that a change in one view is reflected in another. A similar criticism has been levied against DODAF. However, imagine an architecture modeling world without these commonly understood languages and frameworks. UML and DODAF provide mechanisms to capture and represent information in a way that allows multiple stakeholders to reason about complicated concepts. MP offers a similar capability. It does not compete with UML or DODAF, but enhances the toolset available to the architectural modeling community. As an executable architecture model, the MP schema and resulting event traces can be inspected and debugged until the model is considered correct. MP Analyzer on Firebird exports views of the executed event traces, including sequence diagrams and a box and arrow view that assisted in this research.

Each step in the application of the ThreeMetrics methodology results in the representation of information that can be used to inform multiple stakeholders. Figure 13 is an example of an MP event trace for EQ: State Dropdown, representing a sequence diagram that highlights the interaction between roots.

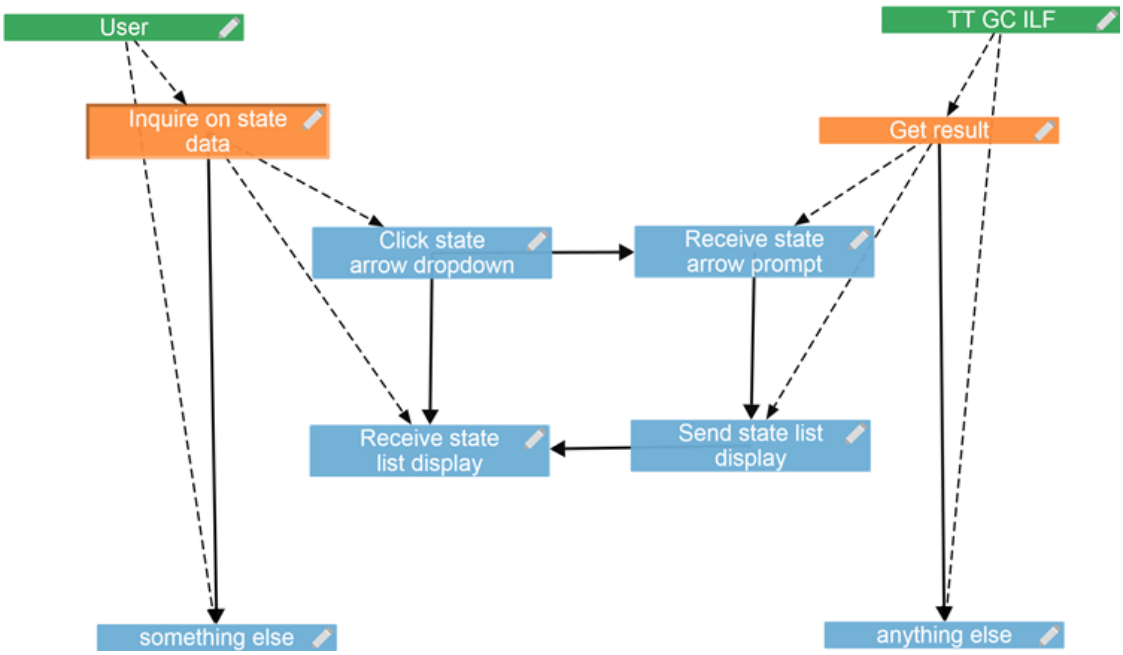


Figure 13. Event Trace View: Sequence Diagram

Figure 14 is an integrated view of the manual and MP schema UFP count calculation. The left side is an example of the UFP done through the current FPA counting methodology and the calculation of the UFP for the EQ transactional function. The right side of Figure 14 shows the representation of the EQ transactional function in an MP schema, with a COORDINATE and ADDs representing the transactional function and the complexity of transactional function EQ. Using both approaches, the UFP count for the EQ transactional function is the same.

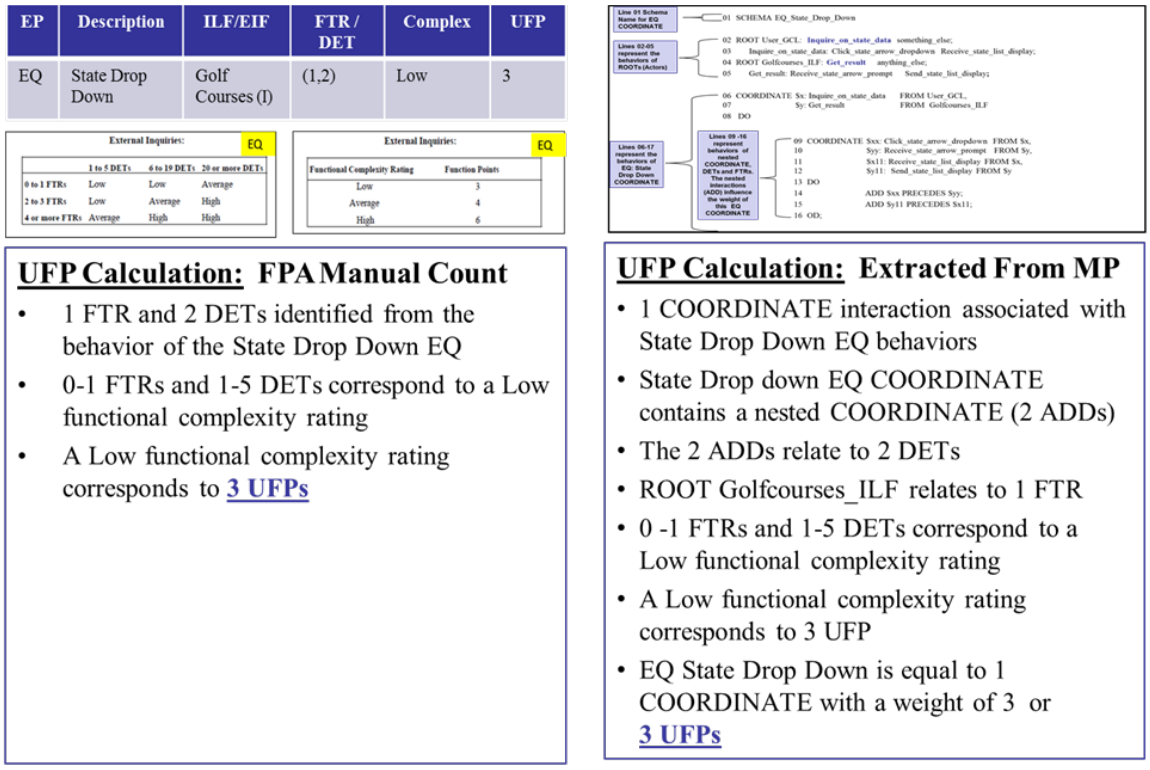


Figure 14. Integrated View of Manual and MP Schema UFP Count Calculation

Recall that Figure 7 is the high-level pseudocode representation of this information. The box and arrow view in Figure 5 where EQ: State Dropdown highlighted is another view of the same information. The COCOMO II model output represents additional information on person-month effort, Schedule, and Cost. Each representation conveys relevant information to different stakeholders.

For more information on the ThreeMetrics Methodology that has been communicated to a broad audience, see previous works in [59]–[68].

IV. IMPLEMENTATION OF METHODOLOGY (EXAMPLES)

This chapter applies each step of the ThreeMetrics methodology described in Chapter III to three examples. The Spell Checker and Course Marks examples are derived from source information from Fenton and Bieman [69]. Variations of the It's Tee Time application, or simply Tee Time, are derived from source information from Q/P Management group [56]. These examples were selected because they contain UFP answer keys that can be compared to the UFP count extracted from the MP model to validate the ThreeMetrics methodology.

The Spell Checker implementation shows that the ThreeMetrics methodology can successfully extract an UFP from an MP model. The source information provided by this example is minimal, but does include an UFP answer key that includes functional complexity and size values for transactional and data function types.

The Course Marks implementation further demonstrates that the ThreeMetrics methodology can extract an UFP count from an MP model. The source information provided is minimal, and it does include an UFP answer key, functional complexity, and size values for transactional and data function types.

The Tee Time implementation highlights the value of detailed source information, which allows the exploration of four Courses of Action (COAs) to determine the UFP count using the ThreeMetrics methodology. Each COA increasingly applies details from the Tee Time source information to develop the MP model:

COA 1:

- Assumes limited source information and therefore average functional complexity and size values for each transactional and data function.
- Inspects model for COORDINATE and SHARE ALL.

COA 2:

- Applies additional detail from source information to develop the MP model.
- Assumes average functional complexity and size values for each transactional and data function.

- Inspects model for EI, EO, EQ, ILF, and EIF descriptive terms associated with COORDINATE and SHARE ALL.

COA 3:

- Applies additional detail from source information to develop the MP model.
- Inspects MP model for each COORDINATE and for each ADD to determine functional complexity and size for transactional functions.
- Inspects model for SHARE ALL and assumes average functional complexity and size for data functions.

COA 4:

- Applies all detail from source information to develop the MP model.
- Inspects the MP model for each COORDINATE and for each ADD to determine functional complexity for each transactional and data function.

The ThreeMetrics methodology is applied to each example in Sections A, B, and C. Since each example includes an UFP answer key in the source information, the ThreeMetrics UFP is then compared to the UFP answer keys to validate the methodology.

Taken together, these implementation examples show that the ThreeMetrics methodology is able to extract an UFP count from MP's executable architecture models for use in software cost estimation. Additionally, the ThreeMetrics methodology uses event traces to inform integration test estimates and decision making, and each step of the methodology provides meaningful information to stakeholders.

A. SPELL CHECKER EXAMPLE

(1) Step 1: Determine stakeholder questions to be answered and gather existing documentation

The Spelling Checker example for the UFP estimate is derived from Fenton and Bieman. The source information was limited, and it includes the diagram reproduced in Figure 15, an UFP answer key, and the following Spell Checker specification information:

> The checker accepts as input a document file and an optional personal dictionary file. The checker lists all words not contained in either of these files. The user can query the number of words and the number of spelling errors found at any stage during processing. [69, pp. 353]

Due to the limited information in the specification, additional assumptions were made to represent the behaviors of the application in the MP model. The checker scans each word of the document. The checker checks if each word is in the spell checker's dictionary. If it is, then the word is spelled correctly. If it is not, the application can check if the word is in the optional personal dictionary. If it is available in the personal dictionary, then the word is spelled correctly. If it is not spelled correctly based on the check with the personal dictionary, the checker provides a set of possible suggestions.

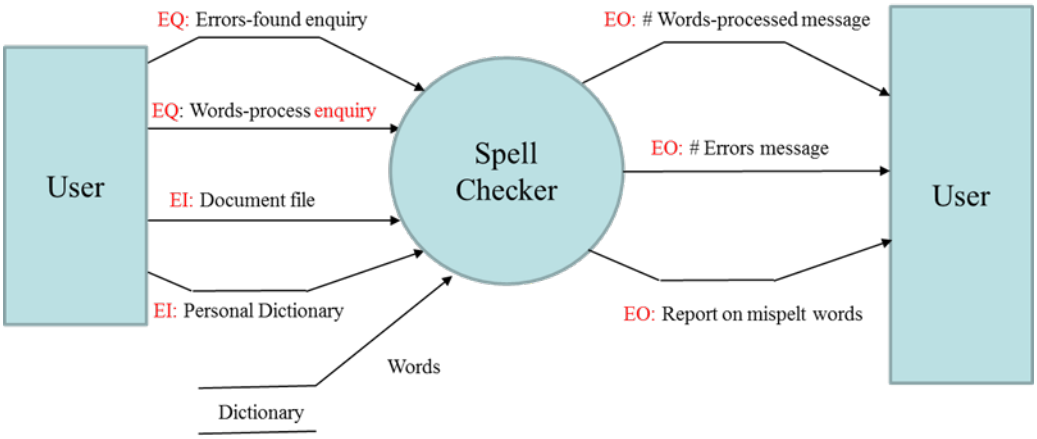


Figure 15. Spell Checker Example. Adapted from [69].

(2) Step 2: Identify scope and application boundary

Based on the source information, the boundary of the application to be counted is identified and highlighted by the red dotted line in Figure 16. Dictionary ILF, Document EIF and Personal Dictionary EIF represent data functions. Transactional functions are represented by EI, EQ, and EO. Additionally, the ThreeMetrics methodology Box and Arrow view serves as a translation point between a function point counting architectural view and an MP architectural view, combining enough relevant information of each methodology to show the initial relationship between both methodologies. A corresponding MP term is identified and associated with each data function and

transactional function, using high-level pseudocode descriptions to refine the natural language descriptions and behaviors from the source information.

The IAA for this example is identified as Spell Chk. The IAA and the Dictionary ILF, are internal to the boundary of the application being counted.

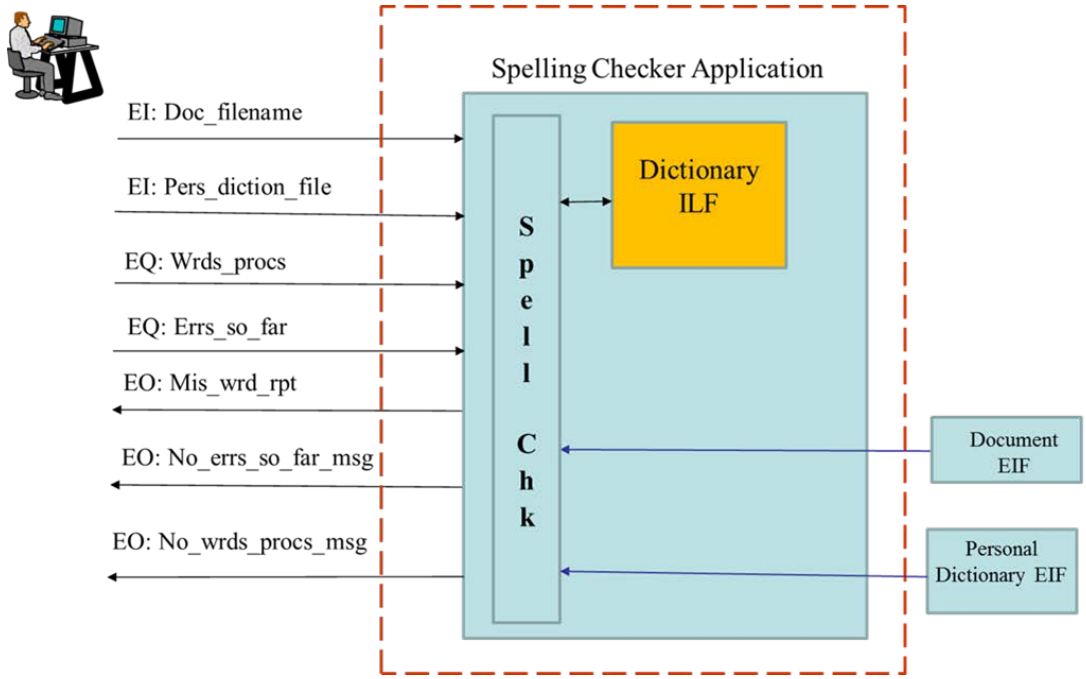


Figure 16. ThreeMetrics Box and Arrow View: Spell Checker

(3) Step 3: Develop MP Model

Once the box and arrow view assists in visualizing the boundary, the actors, the initial behaviors, and interactions, this information can then be further refined by capturing it in an MP model.

The MP schema includes ROOTs for each Actor, the IAA named Spell Chk, and the composition operations that set the conditions to extract the UFP consistent with the methodology identified by the IFPUG counting process. The MP schema Spellchecker_3215 includes the entire model with several highlighted optional behaviors, in a format consistent with FP counting. Since there was such little source information provided, many assumptions were made in order to describe ROOT behaviors in the

model. The MP model was executed using the MP Analyzer on Firebird, resulting in 3,215 event traces.

The complete MP model can be found in Appendix A of this dissertation. An extract is included below to highlight the behaviors of the actors and their interactions.

The user and the spell checker's IAA behaviors are described in the following segment of the MP schema.

```
ROOT User: (*     provide_document_file_name
                        [ provide_personal_dictionary ]
                        [inquire_on_number_of_processed_words]
                        [ check_number_of_processed_words ]
                        [inquire_on_number_of_errors_so_far]
                        [ check_number_of_errors_so_far ]
                        read_spelling_report
                        update_document_file
                        read_errors_message
                        [ update_personal_dictionary ]
                        [receive_misspld_wrd_rpt]
                  *)
                        no_more_errors
                        end_of_work;


ROOT Spell_chk : (*       read_document_file
                        Process_document
                  [send_number_of_processed_words]
                        [ report_number_of_processed_words ]
                  [send_number_of_errors]
                        [ report_number_of_errors ]
                        provide_spelling_report
                        [report_misspld_wrd]
                        *) ;

                  Process_document:       read_dictionary
                                          [ read_personal_dictionary ]
                                          [ spelling_errors_detected ]

                                          ;
```

The EI transactional function type interaction between the user and the Spell_chk IAA is captured in the following EI COORDINATE.

```
/* EI: Doc_filename */

COORDINATE          $pdoc: provide_document_file_name    FROM User,
                    $rdoc: read_document_file            FROM Spell_chk

DO          ADD $pdoc PRECEDES $rdoc;
      OD;
```

The interaction between the Spell_chk IAA and the Dictionary ILF is captured using SHARE ALL.

```
ROOT Dictionary: (* read_dictionary *);

Spell_chk, Dictionary                          SHARE ALL read_dictionary;
```

The .wng files, containing the MP schema and event traces, for the spell checker model will be available on the Monterey Phoenix wiki hosted by the Naval Post Graduate School [47].

(4) Step 4: Extract Data Functions Count from MP model

When there is limited source information available, the data functions can be represented in the MP schema using the SHARE ALL composition operation. This describes the interactions between the IAA and the EIF (Document File and Personal Dictionary) and the ILF (Dictionary).

Through manual inspection of the MP schema for the spell checker example, 3 SHARE ALLs are counted. Since minimal source information is available, the functional complexity is assumed to be average.

(5) Step 5: Extract Transactional Functions count from MP model

Through manual inspection of the MP schema for the spell checker example, seven COORDINATEs are counted. These seven COORDINATES represent transactional function types (EI, EO, EQ). Since minimal source information is available, the functional complexity is assumed to be average.

(6) Step 6: Extract integration test cases and views from MP model

Extracting event traces (i.e., use cases) from an MP schema sets the conditions to verify the model either through manual inspection of the event traces or by leveraging automated tools. The use cases serve as a valuable blueprint for the construction of integration test cases, which can then be used to support integration test estimates.

For this example, Scope 1 was used and considered sufficient. The event traces were inspected and increasing the scope did not show anything new or notable, and would not improve chances of exposing errors in testing.

Recall that the activities associated with a test case includes test steps, preconditions, test data that supports what the test case needs to achieve, expected results, post conditions, information about the environment, infrastructure to support execution of the tests, and analysis of the test results. The event traces generated from an MP model provide solid detailed blueprints, which can be viewed as guidelines for the creation of the integration test cases.

Three examples of the 3215 event traces are illustrated in Figures 17–19. Figure 17, Event Trace #1 of 3125, illustrates very simple but valid behaviors and interactions.

Figure 17. Firebird Spell Checker Event Trace 1 of 3215

Figure 18, Event Trace #1612 of 3215, illustrates an increasing number of behaviors and more complex interactions.

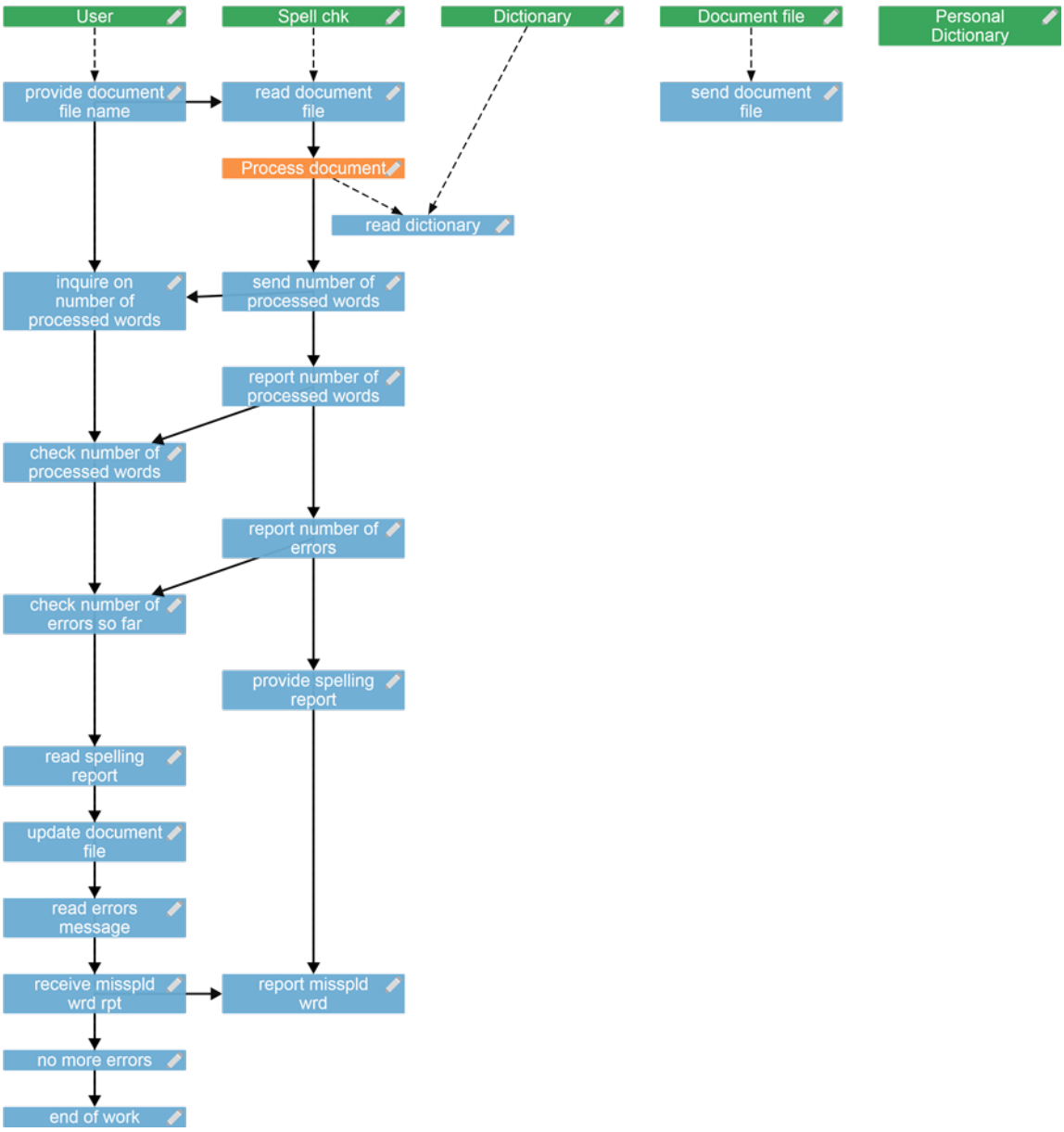


Figure 18. Firebird Spell Checker Event Trace 1612 of 3215

Figure 19, Event Trace #2311 of 3215, illustrates additional behaviors and interactions that are part pf the complete set of event traces.

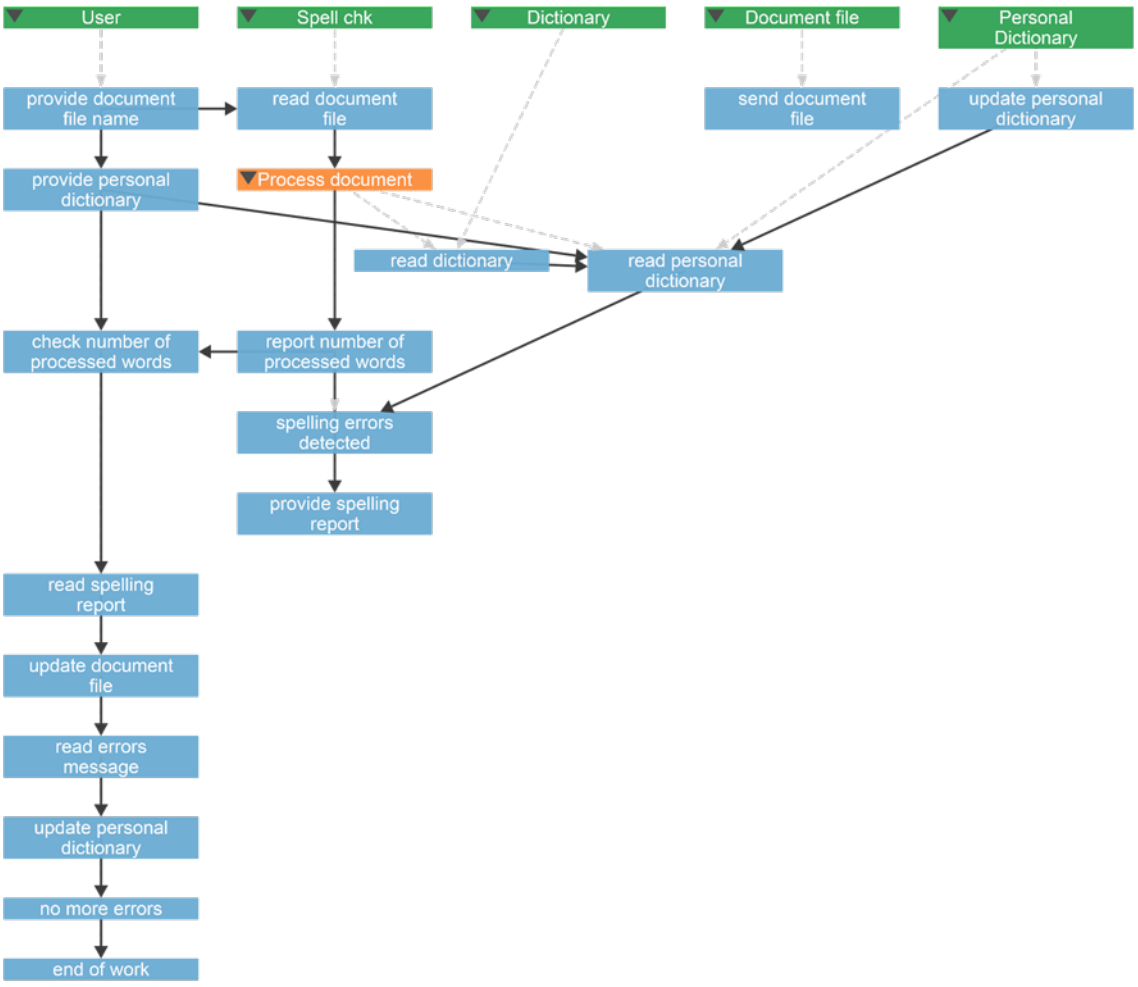


Figure 19. Firebird Spell Checker Event Trace 2311 of 3215

Recall, Brooks indicated he has “successfully used the following rule of thumb for scheduling a software task: 1/3 planning, 1/6 coding, 1/4 component test and early system test, 1/4 system test, all components in hand” [53, p. 20].

.25 x Total effort = Estimate for integration testing

As discussed by Wolff, approximately six integration tests per day can be executed for a large application, such as an electronic commerce system [58, p. 16]. This does not include the amount of time required to create the test case.

Integration test estimates must account for test preparation, including the creation of the test cases and data sets or ensuring that the test environment is ready. The tests do not account for the time required to analyze the results of running the test cases. Additionally, the amount of time required to execute a test case is influenced by the method of execution, i.e., automated using scripts or manually executed, or a combination of both techniques. For several large DOD releases, typically between three and fifteen integration tests per day have been executed, depending on the complexity of the test and the amount of automation. For this research, the value of six test cases per day is used.

In the COCOMO II results that will be discussed in Step 8, the Integration and Test costs are extracted from the phase effort for Construction. In this phase breakdown the total Construction is 76% of the software development effort. Using the waterfall lifecycle definitions for COCOMO II the breakdown is as follows: Product Design 17%; Programming 58%; Integration and Test 25% [55].

As is illustrated by Figure 21 in Step 8, the Construction phase is allocated 4.8 months of schedule. Twenty-five percent of that time is 1.2 months. Those 1.2 months corresponds to 24 days (assuming 5 days per week and 8 hours per day for each staff person). Assuming 6 test cases per day, then 144 test cases can be executed in the allocated time for test and integration.

There are 3215 event traces generated in the MP model. Not including the time required to create and analyze the test cases, this would require over 535 days to execute testing. Upon inspection of the event traces, some are significantly less complicated than others, so test case generation and execution based on each event trace will not require the same amount of effort.

This does provide information for next steps to inform decision making, both technically and programmatically. The first step is to revisit the model, and ensure that

the behaviors of the application are accurately captured. If the model is correct, then the next step is to determine if there is any flexibility in the schedule and resources to support additional testing. Since 535 days is not supportable given current schedule constraints, only a subset of event traces can be selected for testing.

If schedule does not support more than 144 test cases, then the event traces will need to be inspected and a subset selected for use in the creation of test cases. The criteria to determine what subset of event traces to select is a topic for future work.

(7) Step 7: Determine the Unadjusted Function Point (UFP) count

In the case of the example in [69], limited source information is available; so, an assumption is made that the functional complexity for both data and transactional function types corresponds to "average."

The ILF and EIFs identified for this example are:

- ILF: Dictionary
- EIF: Document_file
- EIF: Personal_Dictionary

Based on the tables from the IFPUG, an average functional complexity for an ILF corresponds to 10 UFPs, and an average functional complexity for an EIF corresponds to 7 UFPs.

Note that in the UFP calculation contained in the answer key to the example in [69], the UFP for data functions is shown to be

(2 EIF) x (10 UFP/EIF) + (1 ILF x 7 UFP/ILF) for a total of 27 UFP

According to the functional complexity and functional size values for averages from the IFPUG tables, the UFP count should be:

(2 EIFs) x (7 UFP/EIF) + (1 ILF) x (10 UFP/ILF) = 24 UFP

This difference is noted to point out that the UFP count used for data functions in this analysis will be 24 UFP.

For EI, EO, and EQ, each associated COORDINATE in the MP schema represents a transactional function, resulting in seven transactional functions for this example. For the transactional function UFP count, due to the limited source information available for this example, once again an average functional complexity rating is assumed. According to the IFPUG tables, the corresponding size for an average functional complexity rating is 4 UFPs for an EI, 4 UFP for an EQ, and 5 UFPs for an EO. The transactional functions are:

- EI: Doc_filename
- EI: Pers_diction_file
- EQ: Inquire_errors_so_far
- EO: No_ers_so_far_msg
- EQ: Inquire_words_processed
- EO: No_wrds_prosd_msg
- EO: Misspld_wrd_rpt

2 EI x 4 UFP/EI = 8 UFP

2 EQ x 4 UFP/EQ = 8 UFP

3 EO x 5 UFP/EO = 15 UFP

This results in a total of 31 UFPs for transactional functions. The total UFP count for the Spell Checker example is 31 UFPs + 24 UFPs = 55 UFPs. Recall that for this example, the decision was made to use 24 UFPs for the data functions, so the total UFP is 55 and not 58 as noted in [69].

One of the challenges of inspecting the MP schema is how to address the difference in average functional complexity for an ILF and EIF, if the pseudocode descriptions in the model do not include an ILF or EIF to distinguish between them. One approach is to average the ILF and EIF functional size and suggest that the SHARE ALL functional complexity and size for a data function corresponds to:

Low = (7+5)/2 = 6

Average = (10+7)/2 = 8.5

High = (10+15)/2 = 12.5

This would result in (3 SHARE ALLs) x (8.5 UFP/SHARE ALL) = 25.5 UFPs

The same approach used for data functions can be applied to transactional functions, where EI and EQ have the same value and EO differs:

Low = (3+3+6)/3 = 3.5

Average = (4 +5+4)/3 = 4.5

High = (6+7+6)/3 = 6.5

This would result in (7 COORDINATEs) x (4.5 UFP/COORDINATE) = 31.5 UFPs. Assuming an average complexity, the UFP counts for the data and transactional function types are:

7 COORDINATEs x 4.5 = 31.5 UFP

3 SHARE Alls x 8.5 = 25.5 UFP

This results in a total count of 57 UFPs, which is slightly higher than the 55 UFPs used for this analysis. The remaining challenge is how to assign the low, average, and high functional complexity and size values to the number of COORDINATES, nested COORDINATES and SHARE ALLs, when the requirements are still maturing and the available information is insufficient to accurately describe the DETs, the number of FTRs, and the number RETs.

(8) Step 8: Calculate Effort estimate

Using the total count of 55 UFPs, directly inputting into the COCOMO II tool, and selecting JAVA implementation language, Maintenance Off and a Cost per Person-Month of $20,000, the nominal estimates are synopsized in Table 15, and supported by Figures 20 and 21.

Table 15. Nominal Effort Estimates

Options	Effort	Schedule	Cost	Language	Total Equivalent Size
Nominal Effort Options Selected Maintenance Off	9.5 person-months	7.7 months	$190,695	JAVA	2915 SLOC

Figure 20 illustrates the options available in the COCOMO II model. For this analysis, nominal inputs were selected with 55 UFPs manually inserted into the model.

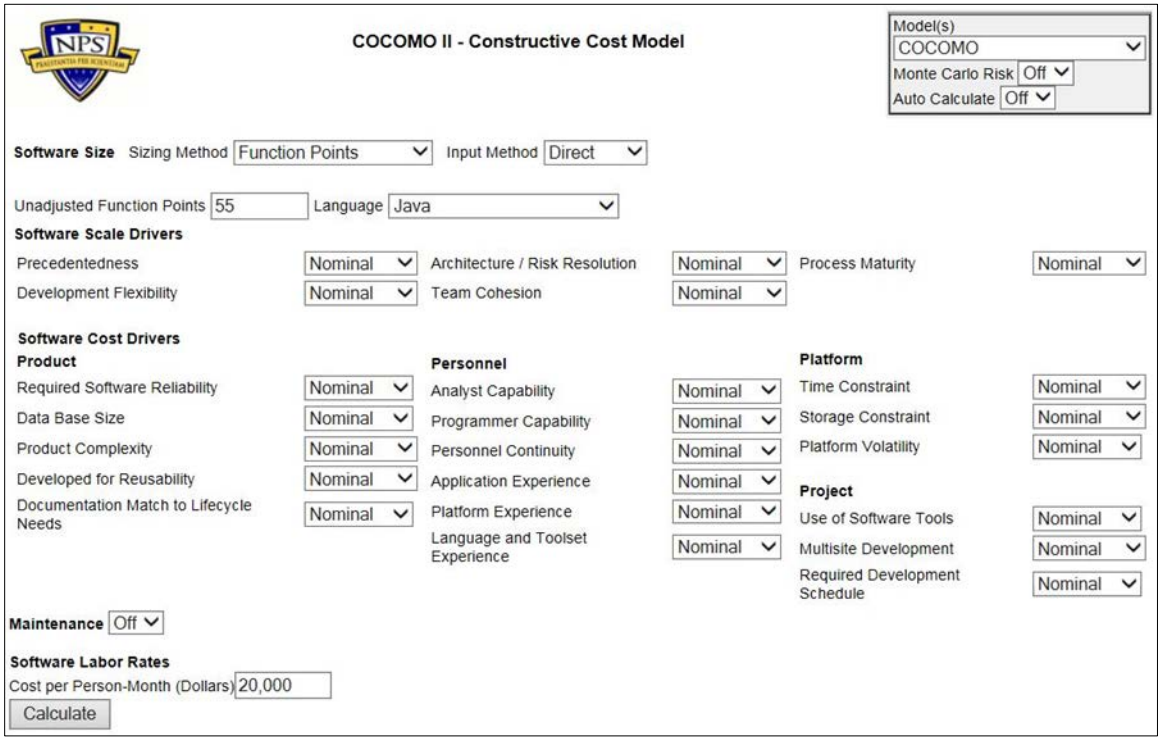


Figure 20. Nominal Effort Options Selected, Maintenance Off

Figure 21 illustrates the results of the COCOMO II model for 55 UFPs manually inserted into the model.

Results

Software Development (Elaboration and Construction)

Effort = 9.5 Person-months
Schedule = 7.7 Months
Cost = $190695

Total Equivalent Size = 2915 SLOC

Staffing Profile

Your project is too small to display a staffing profile due to truncation.

Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	0.6	1.0	0.6	$11442
Elaboration	2.3	2.9	0.8	$45767
Construction	7.2	4.8	1.5	$144929
Transition	1.1	1.0	1.2	$22883

Software Effort Distribution for RUP/MBASE (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	0.1	0.3	0.7	0.2
Environment/CM	0.1	0.2	0.4	0.1
Requirements	0.2	0.4	0.6	0.0
Design	0.1	0.8	1.2	0.0
Implementation	0.0	0.3	2.5	0.2
Assessment	0.0	0.2	1.7	0.3
Deployment	0.0	0.1	0.2	0.3

Your output file is http://csse.usc.edu/tools/MP_COCOMO/data/COCOMO_August_8_2016_04_36_32_642719.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

Figure 21. Nominal Effort Options Selected, Maintenance Off, Results

(9) Step 9: Finalize analysis and provide results to stakeholders.

As discussed earlier, each stakeholder is interested in a slightly different view of the same set of information. However, these views must be consistent with each other, accurately representing a subset of the whole set of information.

Each step of the ThreeMetrics methodology provides meaningful information to stakeholders. Programmers and engineers will appreciate the high-level pseudo code of the MP model in Appendix A, since it describes the behaviors of the application and its internal and external interactions. System and software engineers will appreciate the box and arrow format of the information in Figure 16. Cost analysts and program managers will appreciate the results of the COCOMO II model in Figure 21, as input to resourcing

requirements presented with each instance of the architecture model. Testers will appreciate the use cases (i.e. event traces), and sequence diagrams that inform integration test case creation.

B. COURSE MARKS EXAMPLE

(1) Step 1: Determine stakeholder questions to be answered and gather existing documentation

The Course Marks System example for UFP estimate is derived from Fenton and Bieman [69, pp. 367–368, 546–548]. The source table used terms such as ‘simple’ and ‘complex’ rather than ‘low’ and ‘high’. Based on the limited description associated with the specification, the requirements are listed with the following associated assumptions inserted next to the decompose requirement:

- “The Course Marks application enables a lecturer to enter student marks for a predefined set of courses and students taking those courses” [69]. (Assumption: Lecturer is the User).
- “Marks can be updated” [69]. (Assumption: This means Added. Changed or deleted are not explicitly called out in this example).
- “Lecturers cannot change the basic course information, as the course lists are the responsibility of the system administrator” [69]. (Assumption: This information is provided via drop down menus for courses and then students.
- The system is menu-driven.
- The lecturer (User) selects from a choice of courses (EI: Menu_selct_course_choice)
- The lecturer (User) then selects from a choice of operations (EI: Menu_selct_operation_choice), which are the following:
- Enter coursework marks (EI: Coursework_marks)
- Enter exam marks (EI: Exam_marks).
- Compute averages (Inquire on average grade, and display to user, EQ: Average).
- Produce letter grades (Inquire on letter grades and display to user, EQ: Letter_grades).

- Display information to screen or printer (Report of list of the students, all known marks, grades, averages, EO: EO: List_of_students_marks.

The source information found in [69] has been reproduced from the original and illustrated in Table 16.

Table 16. UFP Calculation. Adapted from Terms from Solutions and Function Point Complexity Weights [69, p. 547].

External Inputs	Complexity	Complexity Weighting *
Menu-selection: course choice	Simple	3
Menu-selection: operation choice	Simple	3
Coursework marks	Simple	3
Exam marks	Simple	3
External Inquiries	**Complexity**	**Complexity Weighting ***
Average	Simple	3
Letter grades	Average	4
External Outputs	**Complexity**	**Complexity Weighting ***
List of student marks, etc.	Average	5
External Files	**Complexity**	**Complexity Weighting ***
None		
Internal File	**Complexity**	**Complexity Weighting ***
Course file database: This contains the course list, student lists, and all known marks and grades	Complex	10

(2) Step 2: Identify scope and application boundary

Based on the source information, the boundary of the application to be counted is identified and highlighted by the red dotted line in Figure 22. Course_file ILF represents the data functions, and there are no EIFs in this example. Transactional functions are represented by the EIs, EQs, and EOs. The ThreeMetrics methodology box and arrow view serves as a translation point between a FP counting architectural view and an MP architectural view, combining enough relevant information of each to show the initial relationship between both methodologies. A corresponding MP term is identified and associated with each data function and transactional function, using high-level

pseudocode descriptions to refine the natural language descriptions and behaviors from the source information.

In this example, the boundary of the application to be counted is highlighted by the red dotted line, and the Course_file ILF and the IAA named Grade Collector are internal to the boundary.

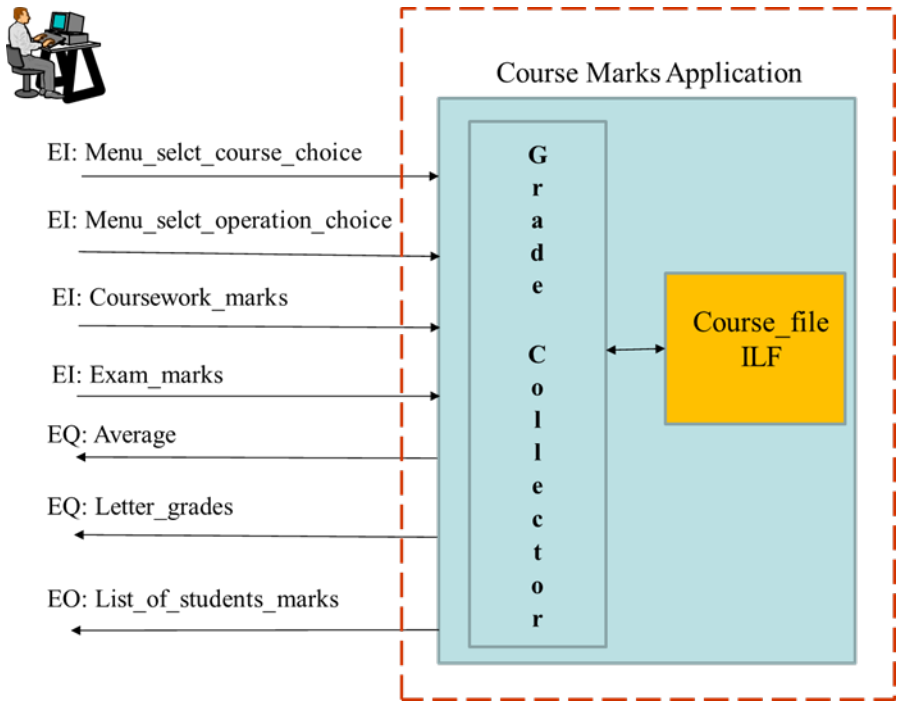


Figure 22. ThreeMetrics Box and Arrow View: Course Marks

(3) Step 3: Develop MP model

Once the box and arrow view assists in visualizing the boundary, the actors, the initial behaviors, and interactions, this information can then be further refined by capturing it in an MP model. The complete MP model for Course Marks can be found in Appendix B. Excerpts that illustrate key points associated with the development of the MP schema are included in this section.

The MP schema includes ROOTs for each Actor, the IAA named Grade Collector, and the composition operations that set the conditions to extract the UFP consistent with the methodology identified by the IFPUG counting process. The complete

MP schema Course Marks includes the entire model in a format consistent with FP counting.

Since there was such little source information provided, several assumptions were made in order to describe ROOT behaviors in the model. The MP model was executed using Firebird, resulting in four event traces.

User and the Grade_collector IAA behaviors are described in the following segment of the MP schema.

```
ROOT User: (* select_course_choice
                    select_operation_choice
                    (enter_coursework_marks | modify_coursework_marks)
                    (enter_exam_marks | modify_exam_marks)
                    inquire_on_average_grade
                    inquire_on_letter_grade
                    receive_student_marks_report
              *)
                    end_of_activity;


ROOT Grade_collector: (* return_course_selection
                              return_operation_selection
                              receive_coursework_marks_input
                              receive_exam_marks_input
                              calculate_average_grade
                              write_average_grade
                              send_average_grade
                              equate_average_grade_to_letter
                              send_letter_grade
                              create_student_marks_report
                              send_student_marks_report

                    *) ;
```

The EI transactional function type interaction between User and the Grade_collector IAA is captured in the following EI COORDINATE.

```
/* EI: Menu_selct_course_choice */
COORDINATE    $pdoc: select_course_choice                    FROM User,
                    $rdoc: return_course_selection                    FROM Grade_collector
    DO              ADD $pdoc PRECEDES $rdoc; OD;
```

The interaction between the Grade_collector IAA and the Coursefile ILF is captured using SHARE ALL.

```
ROOT Coursefile:  (*        receive_coursework_marks_input
                                    receive_exam_marks_input
                                    update_student_exam_mark
                                    update_coursework_mark
                                    write_average_grade
                            *);


Grade_collector, Coursefile        SHARE ALL        receive_exam_marks_input,
                                                    write_average_grade,
                                                    receive_coursework_marks_input;
```

The .wng files, containing the MP schema and event traces, for the Course Marks model will be available on the Monterey Phoenix wiki hosted by the Naval Post Graduate School [47].

(4) Step 4: Extract Data Functions count from MP model

Through manual inspection of the MP schema for the Course Marks example, only one SHARE ALL is counted. This one SHARE ALL represents the data function type (ILF or EIF). This describes the interaction of the Grade_collector IAA and the Coursefile ILF. The functional complexity is provided by the source, which is reproduced in Table 16.

(5) Step 5: Extract Transactional Functions count from MP model

Through manual inspection of the MP schema for the Course Marks example, seven COORDINATEs are counted. The functional complexity is provided by the source, reproduced in Table 16.

(6) Step 6: Extract integration test cases and views from MP model

Extracting event traces (use cases) from an MP schema sets the conditions to verify the model either through manual inspection of the event traces or by leveraging automated tools [33].

Recall that a test case includes test steps, preconditions, and test data that supports what the test case needs to achieve, and also its expected results, post conditions, and information about the environment. The event traces generated from an MP model provide solid detailed blueprints, which can be viewed as guidelines for the creation of the integration test cases.

For this example, Scope 3 was used. Four event traces were generated. The event traces generated for Scope 1 and 2 were inspected and increasing the scope did improve chances of exposing errors in testing.

Figure 23, Event Trace #2 of 4, illustrates the behaviors for the Course Marks application. Figure 24, Event Trace #3 of 4, illustrates the behaviors for the Course Marks application with increasing detail.

Figure 25, Event Trace #4 of 4, illustrates the behaviors for the Course Marks application with increasing detail, but slightly different behaviors represented in this snapshot of a specific use case.

The use cases serve as a valuable blueprint for the construction of integration test cases, which can then be used to support integration test estimates.

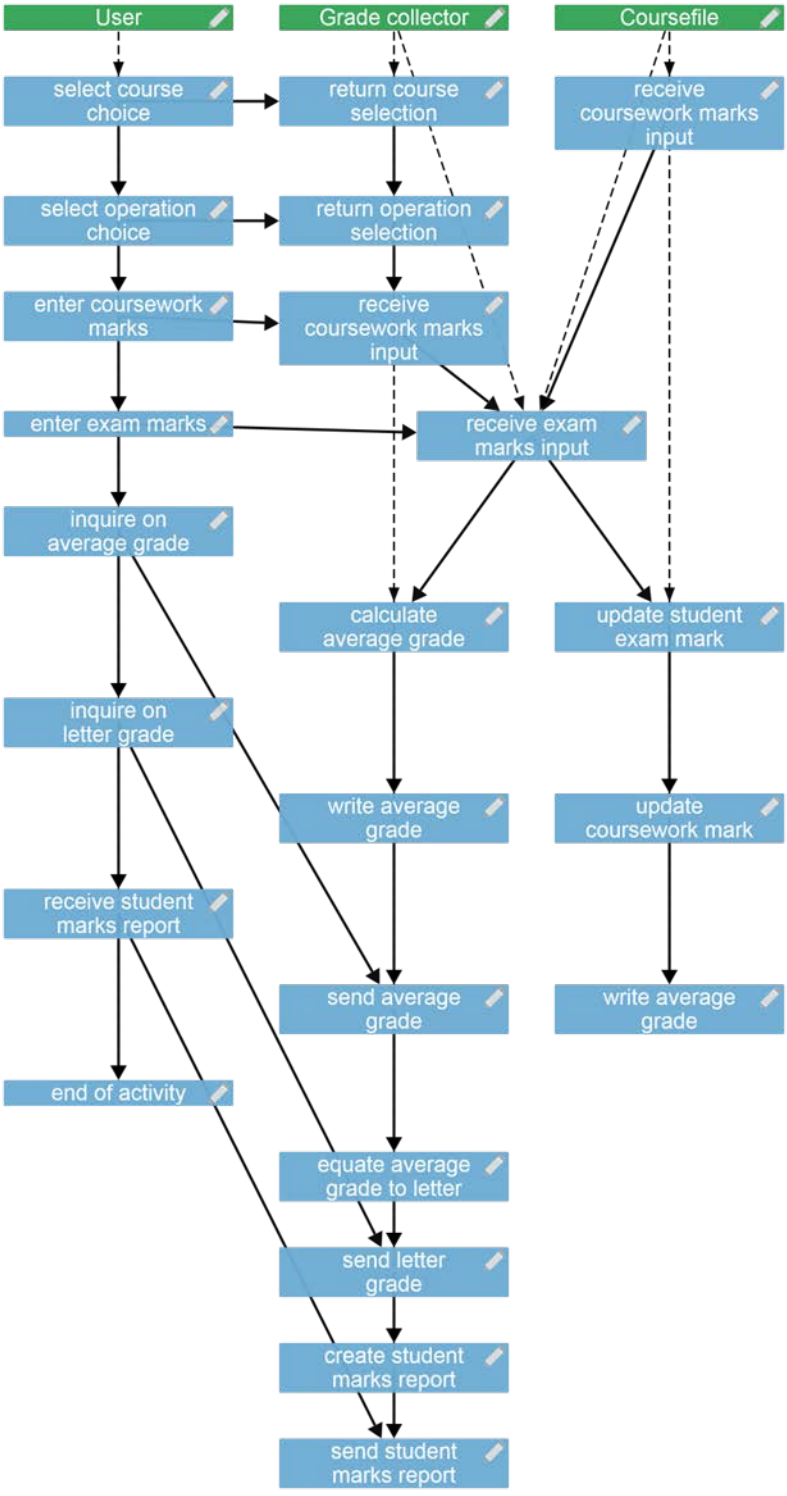


Figure 23. Firebird Course Marks Event Trace 2 of 4

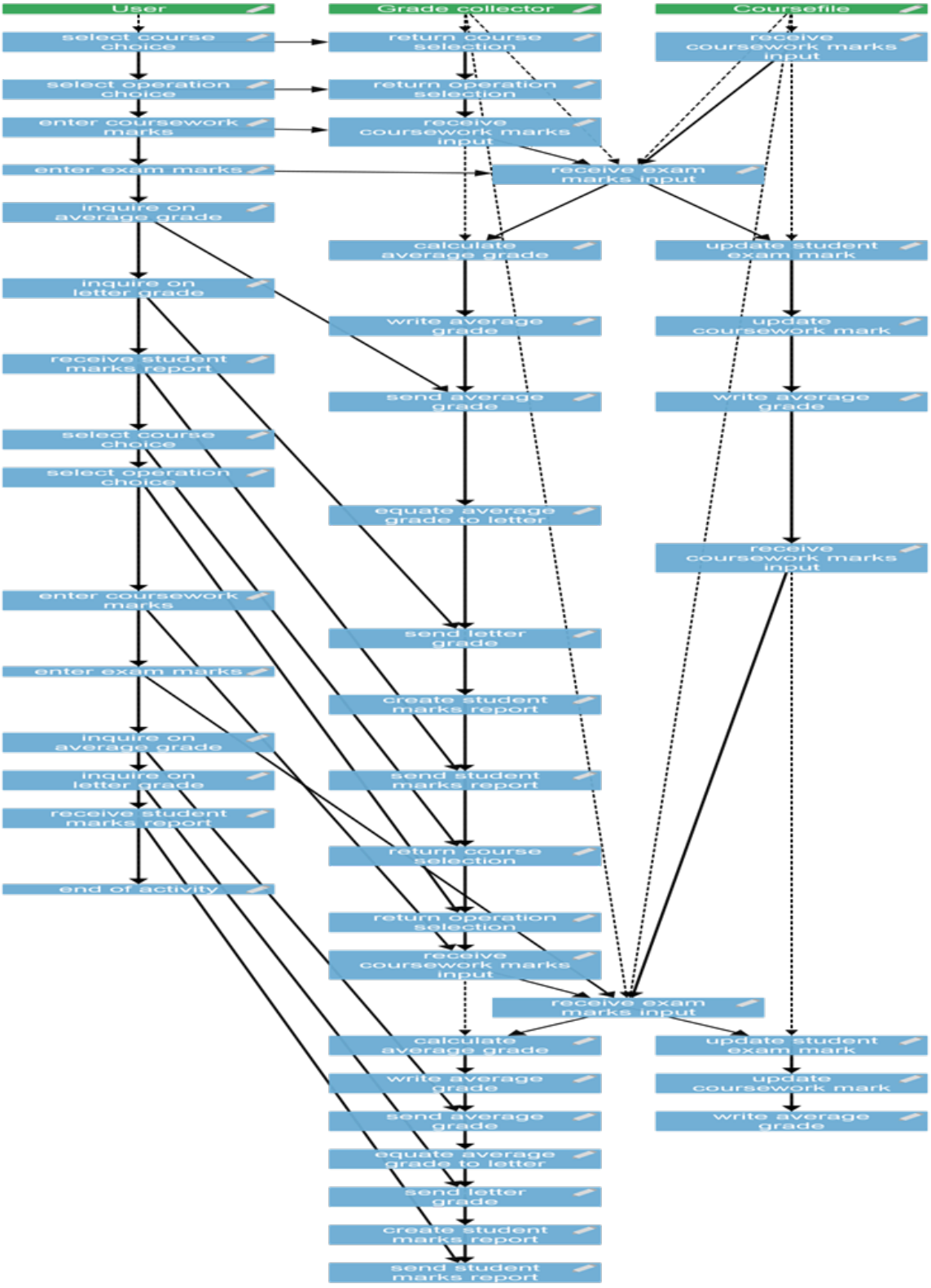


Figure 24. Firebird Course Marks Event Trace 3 of 4

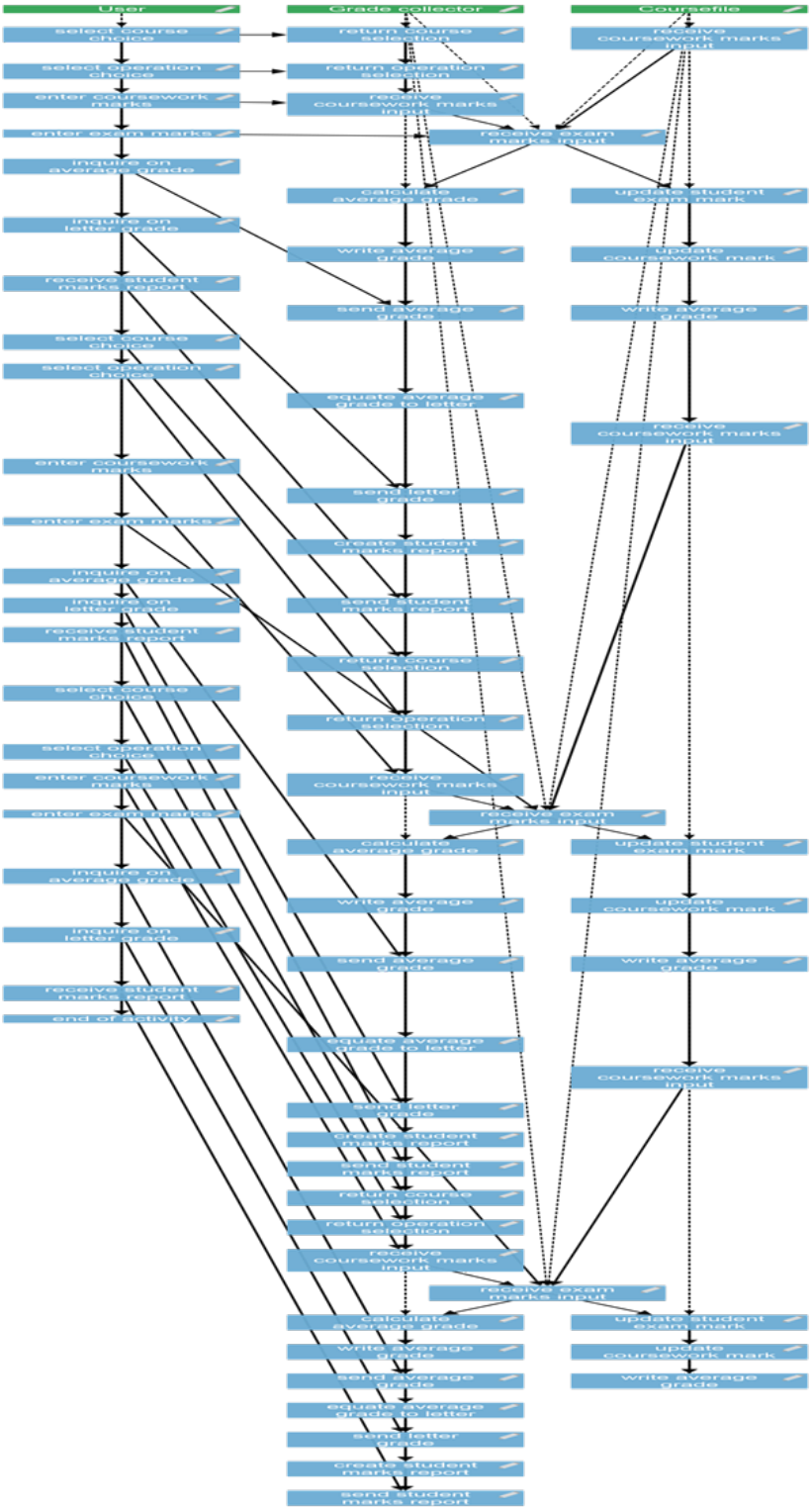


Figure 25. Firebird Course Marks Event Trace 4 of 4

Recall Brooks stated he has “successfully used the following rule of thumb for scheduling a software task: 1/3 planning, 1/6 coding, 1/4 component test and early system test, 1/4 system test, all components in hand” [53, p. 20].

.25 x Total effort = Estimate for integration testing

As discussed by Wolff, approximately six integration tests per day can be executed for a large application, such as an electronic commerce system [58, p. 16]. This does not include the amount of time required to create the test case.

In the COCOMO II results that will be discussed in Step 8, the Integration and Test costs are part of the phase effort for Construction. In this phase breakdown, the total Construction is 76% of the software development effort. Using the waterfall lifecycle definitions for COCOMO II the breakdown is as follows: Product Design 17%; Programming 58%; Integration and Test 25% [55].

As is illustrated in Figure 27, the Construction phase is allocated 4.3 months of schedule. Twenty-five percent of that time is 1.075 months. The 1.075 months corresponds to 21.5 days (assuming 5 days per week and 8 hours per day for each staff person). Assuming that six test cases per day can be executed, then 129 test cases can be executed in the allocated time for test and integration.

There are four event traces generated in the MP model. Not including the time required to create the actual test cases, this would require less than one day to execute all testing. This provides information for next steps to inform decision making, both technically and programmatically. It seems unreasonable to complete testing in one day on this application. The first step is to revisit the model, and ensure that the behaviors of the application are accurately captured, and the model is not overly constrained. If this model is truly representative of the application behaviors, then the next step is to determine how this additional time in the schedule can be re-allocated.

Although Step 6 is focused on integration test case estimates, this step provides an opportunity to confirm that the executable model is not overly constrained. The data and

transactional function types are represented accurately, and the UFP is extracted and calculated correctly, but the event traces suggest the model may need to be revisited to ensure it is constructed properly while maintaining the same relevant information.

(7) Step 7: Determine the Unadjusted Function Point (UFP) count

The source information from [69], illustrated in Table 16, indicates that the data function for ILF Course_file has a functional complexity of "Complex", which is assumed to mean High. This would then correspond to a functional size of 15, from the IFPUG tables. The UFP count for data functions is calculated as follows:

(1 ILF x 15 UFP/ILF) = 15 UFPs

Table 12 also indicates that the transactional functions have functional complexities of simple (assumed to mean low) and average. Using the information from [69] in Table 12 and the IFPUG counting tables, the UFP count for transactional functions is calculated as follows:

(1EI x 3UFP/EI) + (1EI x 3UFP/EI) + (1EI x 3UFP/EI) + (1EI x 3UFP/EI) + (1EQ x 3UFP/EQ) + (1EQ x 4UFP/EQ) + (1EO x 5UFP/EO) = 24 UFPs

The total UFP count is 15 + 24 = 39 UFPs

As discussed earlier, one of the challenges of inspecting the MP schema is how to address the difference in functional complexity for an ILF and EIF. One approach is to average the ILF and EIF functional size and suggest that the SHARE ALL functional complexity and size for a data function (i.e. ILF or EIF) corresponds to:

Low = 6 i.e., (7+5)/2

Average = 8.5 i.e., (10+7)/2

High = 12.5 i.e., (10+15)/2

This would result in (1 SHARE ALL) x (12.5 UFP/SHARE ALL) = 12.5 UFPs.

The same approach used for data functions can be applied to transactional functions:

Low = 3.5 i.e., (3+3+6)/3

Average = 4.5 i.e., (4 +5+4)/3

High = 6.5 i.e., (6+7+6)/3

This results in an UFP total of 36, which is slightly higher than the 34 UFP count found in the source information.

(1EI x 3.5 UFP/EI) + (1EI x 3.5 UFP/EI) + (1EI x 3.5 UFP/EI) + (1EI x 3.5 UFP/EI) + (1EQ x 3.5 UFP/EQ) + (1EQ x 4.5 UFP/EQ) + (1EO x 5UFP/EO) = 24 UFPs

According to the Appendix Solutions to Selected Exercises of [69], the total UFP is 35. According to the solution table in [69] the total UFP is 34. Based on the information provided in the example, the ILF complexity is 'complex' which is assumed to correspond to a functional complexity rating of high. For an ILF with a High functional complexity rating the corresponding number of UFPs should be 15, not 10 as is provided in the solution to the example. Therefore, the UFP count used for this analysis is

(4EI*3UFP/EI) + (1EQ x3UFP/EQ) + (1EQ x 4UFP/EQ) + (1EO x 5UFP/EO) + (1ILF x 15UFP/ILF) = 39 UFPs

(8) Step 8: Calculate effort estimate

Using the total UFP count of 39, and directly inputting into [57] for a JAVA implementation language, Maintenance Off and a Cost per Person-Month of $20,000, results in the nominal estimates synopsized in Table 17 and supported by Figures 26 and 27.

Table 17. Nominal Effort Estimates

Options	Effort	Schedule	Cost	Language	Total Equivalent Size
Nominal Effort Options Selected Maintenance Off	6.5 person-months	6.8 months	$130,664	JAVA	2067 SLOC

Figure 26 illustrates the options available in the COCOMO II model. For this analysis, nominal inputs were selected with 39 UFPs manually inserted into the model.

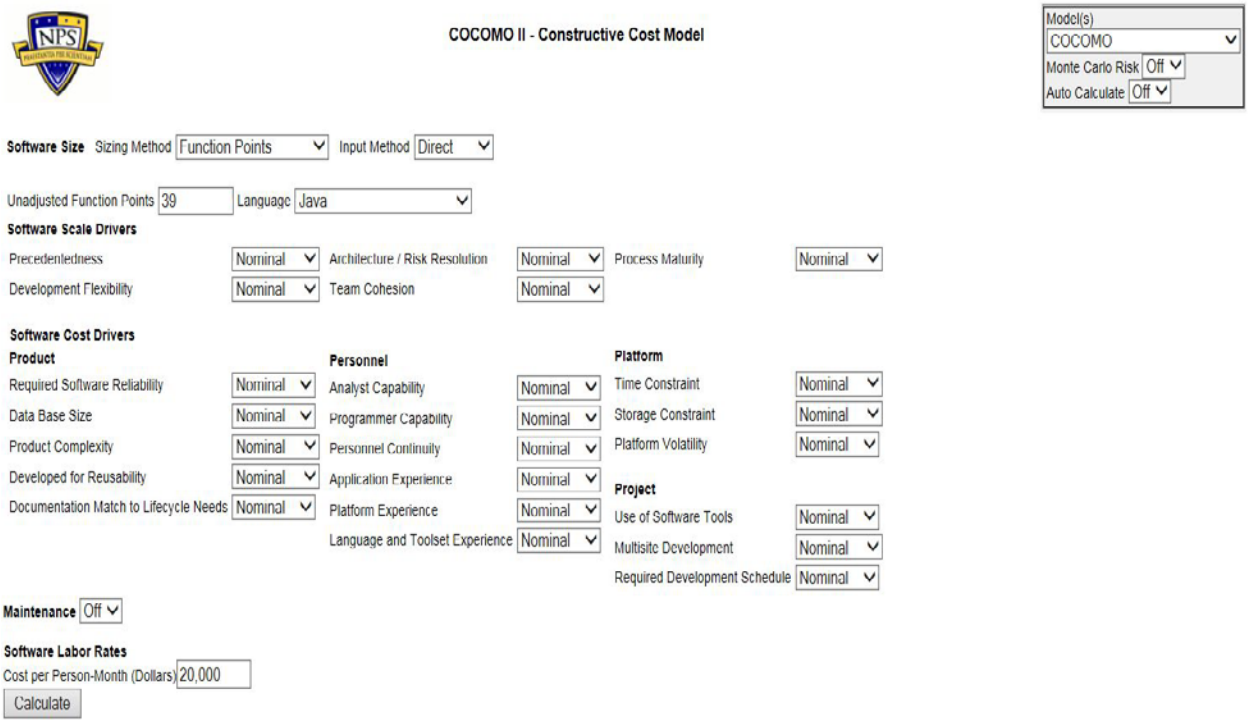


Figure 26. Nominal Effort Options Selected, Maintenance Off

Figure 27 illustrates the results of the COCOMO II model for 55 UFPs manually inserted into the model.

Results

Software Development (Elaboration and Construction)

Effort = 6.5 Person-months
Schedule = 6.8 Months
Cost = $130664

Total Equivalent Size = 2067 SLOC

Staffing Profile

Your project is too small to display a staffing profile due to truncation.

Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	0.4	0.9	0.5	$7840
Elaboration	1.6	2.6	0.6	$31359
Construction	5.0	4.3	1.2	$99305
Transition	0.8	0.9	0.9	$15680

Software Effort Distribution for RUP/MBASE (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	0.1	0.2	0.5	0.1
Environment/CM	0.0	0.1	0.2	0.0
Requirements	0.1	0.3	0.4	0.0
Design	0.1	0.6	0.8	0.0
Implementation	0.0	0.2	1.7	0.1
Assessment	0.0	0.2	1.2	0.2
Deployment	0.0	0.0	0.1	0.2

Your output file is http://csse.usc.edu/tools/MP_COCOMO/data/COCOMO_August_8_2016_06_17_57_415141.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

Figure 27. Nominal Effort Options Selected, Maintenance Off, Results

(9) Step 9: Finalize analysis and provide results to stakeholders

As discussed earlier, each stakeholder is interested in a slightly different view of the same set of information. However, these views must be consistent with each other, accurately representing a subset of the whole set of information.

Each step of the ThreeMetrics methodology provides meaningful information to stakeholders. Programmers and engineers will appreciate the high-level pseudo code of the MP model in Appendix B, since it describes the behaviors of the Course Marks application and its internal and external interactions. System and software engineers will appreciate the box and arrow format of the information in Figure 22. Cost analysts and

program managers will appreciate the results of the COCOMO II model in Figure 27, as input to resourcing requirements presented with each instance of the architecture model. Testers will appreciate the use cases (i.e., event traces) in Figures 23–25, and the sequence diagrams view that inform integration test case creation.

C. IT'S TEE TIME EXAMPLE

The It's Tee Time golfing application example, or simply Tee Time, is derived from the It's Tee Time case exercise. Tee Time source information is protected by copyright, and has been graciously provided by Q/P Management Group, Inc [56] for use in this research. This case study contains detailed source information and an UFP count answer key for the exercise. It has been expanded upon, with guidance and input from Ms. Lori Holmes-Limbacher.

The Tee Time example includes a rich amount of source information, which is used to explore four Courses of Action (COAs). Each COA represents a different model and analysis of the behaviors of the Tee Time application, based on interpretation of the source data. This demonstrates the key aspect of the research by showing that by comparing outputs an analysis can be done on the UFP count extracted from the MP model, how the count for each COA compares to the original case study UFP count, and how the UFP and use cases extracted from the MP model affect the effort estimates.

In COA 1, the goal is to calculate the UFP count for all transactional functions and data functions assuming an average complexity (i.e., functional complexity and size from the IFPUG tables) for all transactional and data functions. The transactional functions are extracted based on manual inspection of the model for the number of COORDINATES. The data functions are extracted based on manual inspection of model for the number of SHARE ALLs.

In COA 2, the goal is to calculate the UFP count for all transactional functions and data functions, and extract transactional functions based on manual inspection of the model for the number of COORDINATES. Data function types are extracted based on manual inspection of model for the number of SHARE ALLs. The COORDINATEs are distinguished by words such as "inquire" or "view" for EQ, "add", "change", or "delete"

for EI, and “calculate” or “buy” for EO. For data functions, search for the number of ILFs associated with SHARE ALL and number of EIFs associated with SHARE ALLs. Assume an average functional complexity and size for each transactional and data function type. The IFPUG tables are then used to assign functional complexity and size values for each transactional and data function type.

In COA 3, the goal is to calculate the UFP count for all transactional functions and data functions, extracting transactional function types based on manual inspection of the MP model for the number of COORDINATES, and utilizing nested COORDINATEs (i.e., counting the number of ADDs per COORDINATE) to more accurately represent the DETs. The data function types are extracted based on manual inspection of model for the number of SHARE ALLs. The IFPUG tables are then used to assign functional complexity and size values for each transactional and data function type.

In COA 4, the goal is to calculate the UFP count for all transactional functions and data functions, using nested COORDINATEs to represent both function types. The process includes extracting transactional functions and data functions based on manual inspection of the MP model for the number of COORDINATES, and utilize nested COORDINATEs (count the number of ADDs per COORDINATE). The IFPUG tables are then used to assign functional complexity and size values for each transactional and data function type.

COA 1 and COA 2 will both leverage the same MP SCHEMA TeeTime_COA1_COA2.

COA 3 will leverage the MP SCHEMA named MP SCHEMA TeeTime_ Nested_COORDINATEs_SHARE ALL.

COA 4 will leverage the MP SCHEMA TeeTime_Nested COORDINATEs_Trans_Data.

Steps 1 and 2 of the ThreeMetrics methodology are common to COA 1, 2, 3 and 4. Step 3 of the ThreeMetrics methodology is common to COAs 1 and 2. Steps 4 through 9 illustrate how additional detail in the source data affect the UFP count.

(1) Step 1: Determine stakeholder questions to be answered and gather existing documentation

Organization A is performing application counts as part of internal cost and management controls. The application It's Tee Time, source information protected by copyright, is being counted and includes several prototyped screens and high-level functional requirements. The following figures and descriptions comprise the source information associated with this application, provided by Q/P Management Group, Inc [56]. Additional refinement of the requirements resulting in the detailed UFP count was obtained through discussions with a subject matter expert.

Figure 28 illustrates the It's Tee Time screen. Behaviors associated with this screen are:

- Press Start to continue to the next screen or
- Press exit to leave the system

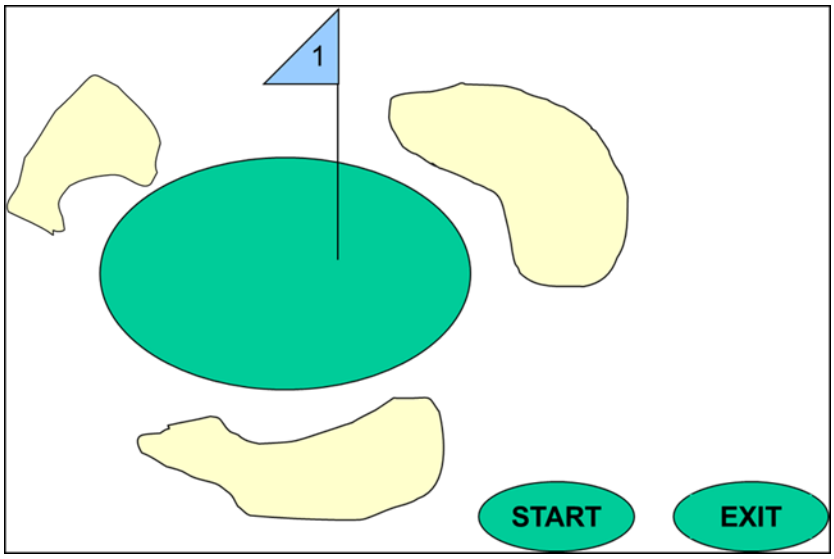


Figure 28. It's Tee Time Screen. Adapted from [56].

Figure 29 illustrates the Tee Time Main Menu screen. Behaviors associated with this screen are:

- Golf Courses List takes you to Golf Course List screen
- Golf Courses Maintenance takes you to Maintain Golf Course screen
- Scoreboard takes you to Scoreboard screen
- Tee Time Shopping takes you to TeeTime Shopping screen

Figure 29. Tee Time Main Menu Screen. Adapted from [56].

Figure 30 illustrates the Golf Course List Screen. Behaviors associated with this screen are:

- You are required to enter a State and City from the Drop downs
- Hitting Display shows the list on the bottom of the page
- Drop downs come from cities and states in the Golf Courses database
- City Drop down is based on what State was entered
- Select a Golf Course from the list to go to Golf Course Detail screen

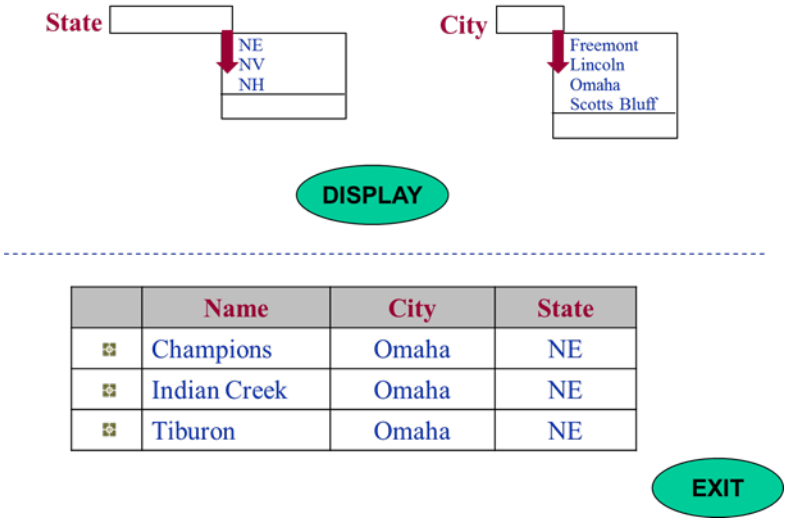


Figure 30. Golf Course List. Adapted from [56].

Figure 31 illustrates the Golf Course Detail Screen. Behaviors associated with this screen are:

- Select BACK to return to selection screen
- Select DIRECTIONS to navigate to MapQuest
- Select TEE TIME Reservation to go to that screen

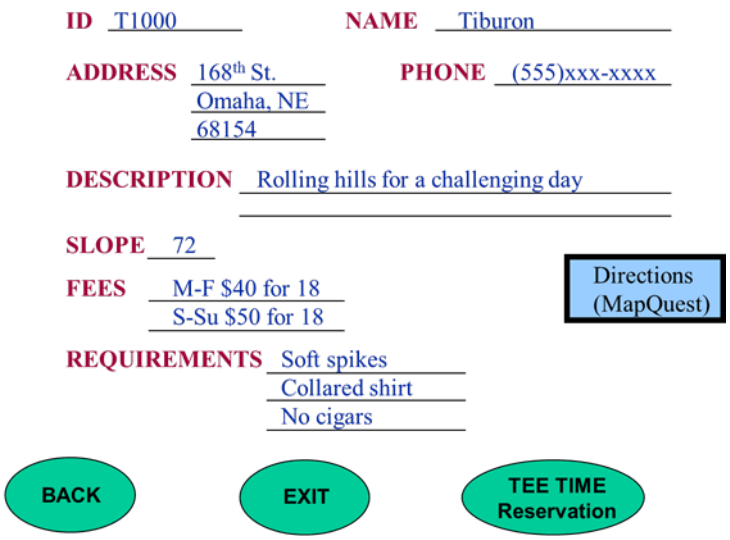


Figure 31. Golf Course Detail. Adapted from [56].

Figure 32 illustrates the Tee Time Reservation screen. Behaviors associated with this screen are:

- ID and Name are carried from the previous screen
- Use hard coded DATE drop down to select a date
- Click DISPLAY to show current tee times on the bottom of the page
- Enter in new tee times on blank rows and click ADD
- Change information in existing tee times and click CHANGE
- Highlight Time field and click DELETE to remove tee time

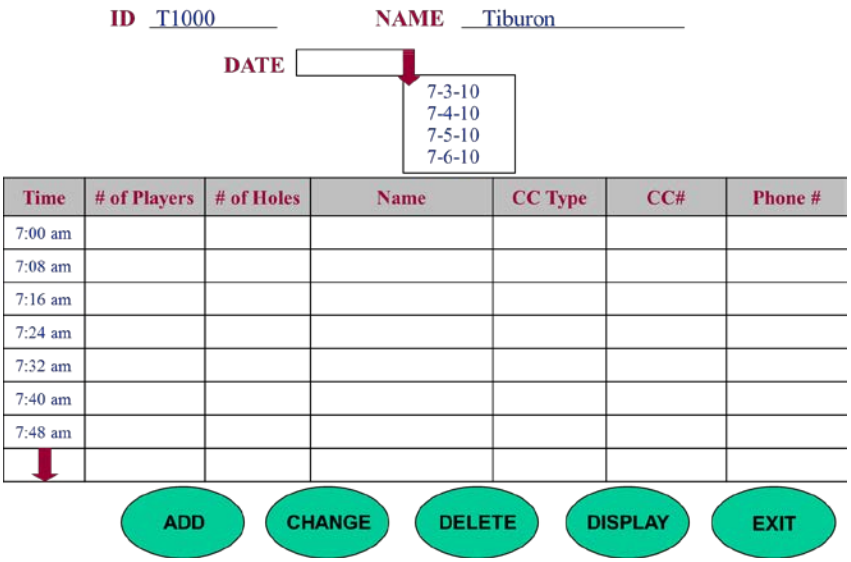


Figure 32. Tee Time Reservation Screen. Adapted from [56].

Figure 33 illustrates the Maintain Golf Courses screen. Behaviors associated with this screen are:

- Enter information in blank screen and click ADD for new courses
- Enter ID or Name and click DISPLAY to show information
- Change information and click CHANGE for modifications

  Click DELETE to remove (edit to make sure there are no tee times)

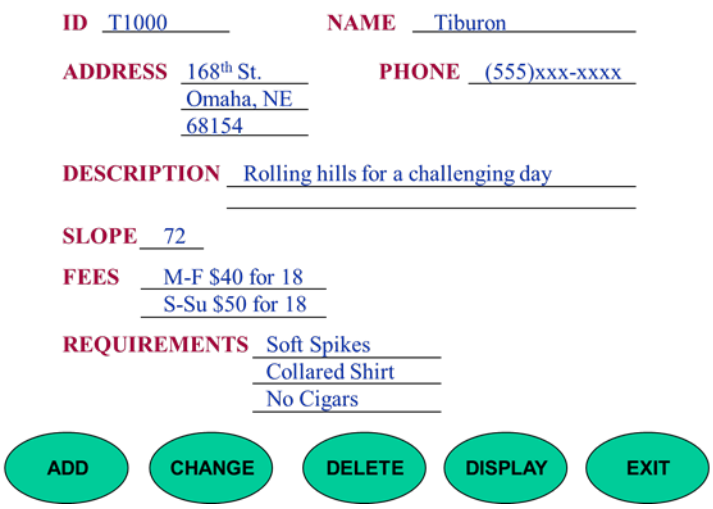


Figure 33. Maintain Golf Courses Screen. Adapted from [56].

Figure 34 illustrates the Scoreboard screen. Behaviors associated with this screen are:

- Selecting from the Main Menu results in this display
- Enter information in a blank line and click ADD for new scores
- Change information and click CHANGE for modifications
- Highlight Name and Click DELETE to remove

Name	Course	Date	Slope	Score
R. Heller	Tiburon	7-3-10	72	75
J. Furyk	Tiburon	7-3-10	72	95
C. Kerr	Tiburon	7-3-10	72	74
L. Holmes	Tiburon	7-3-10	72	70

Figure 34. Scoreboard Screen. Adapted from [56].

Figure 35 illustrates the Tee Time Shopping screen. Behaviors associated with this screen are:

- Selection from the Main Menu results in this screen
- Initial display shows products and unit prices from Marketing system
- As quantities are entered, the totals are calculated
- Once all data is entered click BUY to send a record to purchasing
- Click View button to display a picture of the product

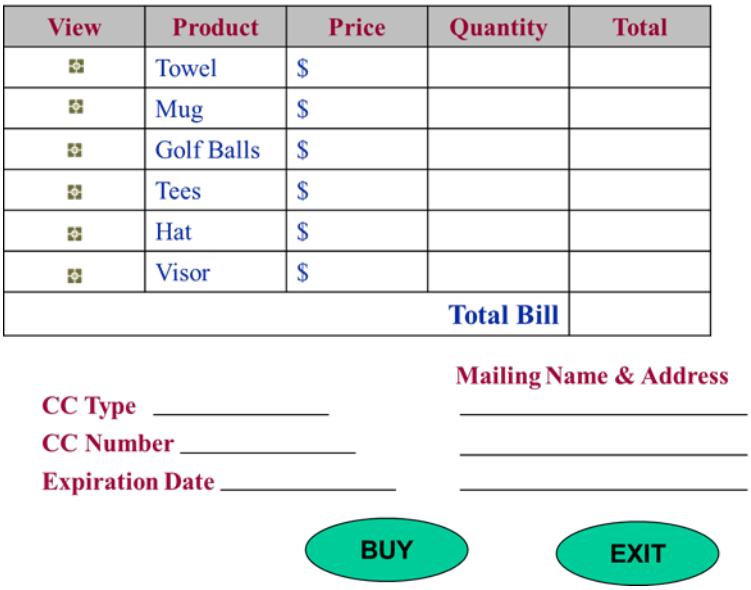


Figure 35. Tee Time Shopping. Adapted from [56].

Figure 36 illustrates the Tee Time Merchandise Example screen. Behaviors associated with this screen are:

- Press Back to return to the Tee Time Shopping screen
- Press Exit to leave the system

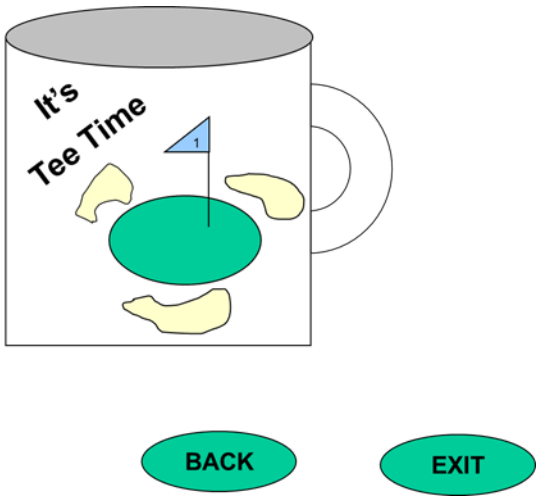


Figure 36. Tee Time Merchandise Example Screen: Mug. Adapted from [56].

Figure 37 illustrates the Tee Time database layout for Internal Logical Files, identified in the Tee Time source data.

Figure 37. Database Layout: Internal Logical Files. Adapted from [56].

Figure 38 illustrates the Tee Time database layout for the External Interface File, identified in the Tee Time source data.

Figure 38. Database Layout: External Internal Interface Files. Adapted from [56].

The answer key for the Tee Time application was included in the source information provided by Q/P Management Group [56] for this research. The total UFP count is 88.

(2) Step 2: Identify scope and application boundary

After the source information is studied and interpreted, the next step is to create a view of the information that can be used to identify the boundary of the application being counted, represent the Internal Abstracted Application, in this case TT, represent the EIFs and ILFs, and the EIs, EOs, EQs. This view is represented by Figure 39.

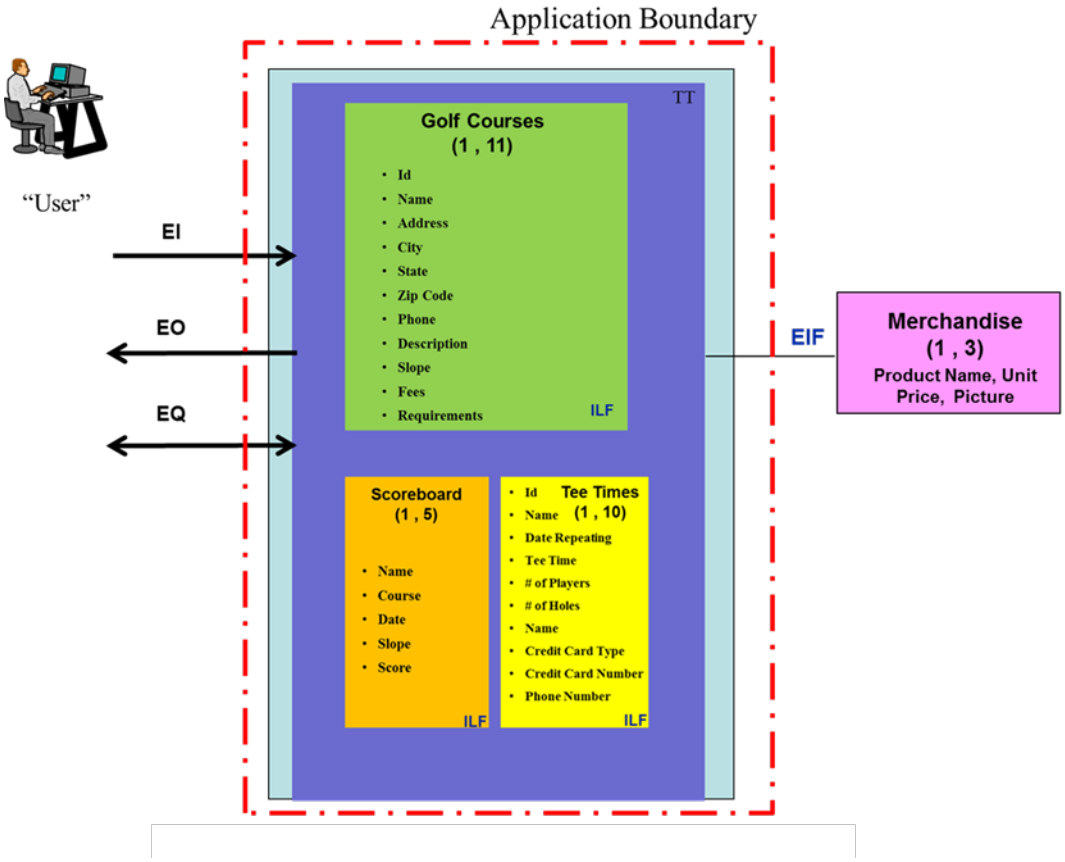


Figure 39. ThreeMetrics Box and Arrow View: Tee Time

The initial abstraction illustrated in Figure 39 does not contain enough information to complete the MP model, but it does contain enough information to begin to construct key abstracted portions of it. There are a total of 10 ROOTs that can be identified based on the User, the EIF, and the application being counted. The Tee Time application is being counted, and is contained within the application boundary depicted by the red dashed line. Internal to the Tee Time application are three ILFs (Golf Courses

ILF, Scoreboard ILF, Tee Times ILF) and the Internal Abstracted Application referred to as TT (everything not the ILFs). The ROOTs are:

- ROOT User
- ROOT TT_GC_ILF
- ROOT TT_Teetimes_ILF
- ROOT TT_Scoreboard_ILF
- ROOT TT_Merchandise_EIF
- ROOT TT
- ROOT GC_ILF
- ROOT Teetimes_ILF
- ROOT Scoreboard_ILF
- ROOT Merchandise_EIF

Five of the ten ROOTs have been created to address the interactions between the IAA and the Internal Logical Files and External Interface Files, to support the data function UFP count. ROOT TT_GC_ILF, ROOT TT_Teetimes_ILF, ROOT TT_Scoreboard_ILF, and ROOT TT_Merchandise_EIF represent the combination of behaviors between the Internal Abstracted Application (IAA) and the ILFs and EIFs as seen by ROOT User. For example, ROOT_TT_GC ILF represents the combined behaviors of the TT IAA and the Golf Courses ILF (GC_ILF), as the ROOT_TT_GC_ILF interacts with the behaviors of the User.

(3) Step 3: Develop MP model

COA 1 and COA 2 share the same MP model named MP SCHEMA TeeTime_COA1_COA2, but the MP model is inspected differently, resulting in different UFP counts. COA 2 takes advantage of source information to create more precise descriptions of behaviors, and then uses key words in the inspections process to assist in determining the overall UFP count.

COA 3 uses MP SCHEMA TeeTime_ Nested_COORDINATEs_SHARE ALL named introduces the use of nested COORDINATEs for transactional function types. The data functions are still represented by SHARE ALL.

COA 4 leverages MP SCHEMA TeeTime_Nested COORDINATEs_Trans_Data. The MP schema from COA 3 is re-used for transactional function types, but the behaviors of the data function types are represented using nested COORDINATEs.

COA 1 and COA 2: For COA 1 and COA 2, the behaviors of each ROOT are captured by specific activities associated with each ROOT, as described by the requirements, supporting information, and the ThreeMetrics box and arrows representation. The interactions between the User, the IAA, and the ILFs and EIF are captured by utilizing the COORDINATE composition operation for the transactional functions and SHARE ALL composition operation for the data functions. An average functional complexity and size are assumed for the transactional and data function types.

The behaviors of the ROOTs are described using specific words associated with transactional function types EI, EO, EQ.

- If the words inquire_on are used in the description of a behavior, then the behavior is associated with an EQ.
- If the words input_add, input_change, or input_delete are used in the description of a behavior, then the behavior is associated with an EI.
- If the word calculate is used in the description of a behaviors, then the behavior is associated with an EO.

The assignment of an EI, EO, or EQ to a COORDINATE is based on the high-level pseudo code used to describe the behaviors. This becomes important when

distinguishing between the IFPUG functional complexity and size values of an EI, EO, or EQ.

The ROOT User behaviors (representing the User) and the ROOT TT_GC_ILF behaviors (representing the combined, relevant behaviors of the IAA and Golfcourses ILF), and the ROOT TT_Merchandise_EIF (representing the combined, relevant behaviors of the IAA and Merchandise EIF) are described in the following extract of the MP Schema.

```
ROOT User: (* ( (inquire_on_state_data
                                inquire_on_city_data
                                inquire_on_golfcourse_list
                                (* (inquire_on_golfcourse_detail | go_back )*)
                                inquire_on_reservation_display
                                (input_add_reservation_data |
 input_change_reservation_data |
 input_delete_reservation_data)
                                        inquire_on_maintain_golfcourses
                                        (input_add_maintain_golfcourses_data |
          input_change_maintain_golfcourses_data |
 input_delete_maintain_golfcourses_data) )
                               inquire_on_scoreboard_display
                                (input_add_scoreboard_data |
 input_change_scoreboard_data |
 input_delete_scoreboard_data)
                                        inquire_on_shopping_display
                                        (* (inquire_on_product_display
 calculate_total_amount
 buy_product )*)

                                                                        | exit)
                                        *);

ROOT TT_GC_ILF: (* (get_state_result
                                        get_city_result
                                        get_golfcourse_list_result
                                        get_golfcourse_detail_result
                                        get_maintain_golfcourses_result
                                        (*(add_maintain_golfcourses_data |
                        change_maintain_golfcourses_data |
                        delete_maintain_golfcourses_data)*) )


                                *);
```

```
ROOT TT_Merchandise_EIF: ( get_shopping_display_result
                                        (*(get_product_display_result
                                        get_calculated_total_amount
                                        send_calculated_amount_to_purchasing)*)
                                );
```

Behaviors representing the interaction between the User and the TT_GC_ILF and the User and the TT_Merchandise_EIF are captured in COORDINATEs 1-20 of the MP schema for transactional functions.

Since COORDINATE 1 includes the words inquire_on, it is considered an EQ transactional function. Its functional complexity and size are found in the IFPUG tables for an EQ transactional function.

```
/* COORDINATE 1: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE $a:inquire_on_state_data          FROM User,
                    $b:get_state_result              FROM TT_GC_ILF

DO      ADD $a PRECEDES $b;OD;
```

COORDINATE 6 includes the words input_add. It is considered an EI transactional function, and its functional complexity and size are found in the IFPUG tables for an EI.

```
/* COORDINATE 6: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE    $k:input_add_reservation_data          FROM User,
                $l:add_reservation_data          FROM TT_Teetimes_ILF

      DO ADD $k PRECEDES $l; OD;
```

COORDINATE 19 includes the word calculate. It is considered an EO transactional function, and its functional complexity and size are found in the IFPUG tables for an EO transactional function.

```
/* COORDINATE 19: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE $kk:calculate_total_amount                FROM User,
                $ll:get_calculated_total_amount          FROM TT_Merchandise_EIF

DO      ADD $kk PRECEDES $ll;OD;
```

The complete MP Schema for COA 1 and COA 2 are found in Appendix C sections 1 and 2, respectively.

COA 3: The MP schema for COA 3 introduces the use of nested COORDINATEs. The behaviors of each ROOT are captured by specific activities associated with each ROOT, as described by the requirements, supporting information, and the box and arrows representation.

For COA 3, the interactions between the IAA, the ILFs and EIF are still captured by utilizing the SHARE ALL composition operation for the data functions. An average functional complexity is still assumed for the data functions.

However, COA 3 begins to leverage the detailed Tee Time source information to represent additional behaviors of each DET internal to each transactional function type, in the form of each ADD in a nested COORDINATE. Since sufficient information is available to determine the actual functional complexity and size, it is no longer necessary to assume an average functional complexity and size for the transactional functions.

The methodology used in COA 1 and 2 to create the MP schema is used as a starting point in COA 3. The behaviors of the ROOTs continue to be described using specific words associated with transactional functions EI, EO, EQ. The description of the behaviors is then expanded, to take advantage of composite events in the ROOTs and the additional behaviors of DETs. The behaviors associated with each DET are captured in the ROOTs, and the interaction is represented as an ADD within the nested COORDINATE.

The ROOT User behaviors (representing the User) and the ROOT TT_GC_ILF behaviors (representing the combined, relevant behaviors of the IAA and Golfcourses ILF) are described in the following extract of the MP Schema for COA 3.

```
ROOT User: (* ( (inquire_on_state_data
                        inquire_on_city_data
                        inquire_on_golfcourse_list
                        (* (inquire_on_golfcourse_detail | go_back )*)
                        inquire_on_reservation_display
                        (input_add_reservation_data |
input_change_reservation_data |
input_delete_reservation_data)
                                inquire_on_maintain_golfcourses
                                (input_add_maintain_golfcourses_data |
input_change_maintain_golfcourses_data |
input_delete_maintain_golfcourses_data) )
                        inquire_on_scoreboard_display
                         (input_add_scoreboard_data |
input_change_scoreboard_data |
input_delete_scoreboard_data)
                                inquire_on_shopping_display
                                (* (inquire_on_product_display
calculate_total_amount
buy_product )*)
                                                                | exit)
            *);


inquire_on_state_data: click_state_arrow_dropdown        receive_state_list_display;
ROOT TT_GC_ILF: (* (get_state_result
                                get_city_result
                                get_golfcourse_list_result
                                get_golfcourse_detail_result
                                get_maintain_golfcourses_result
                                (*(add_maintain_golfcourses_data |
            change_maintain_golfcourses_data |
            delete_maintain_golfcourses_data)*) )

                        *);

get_state_result: receive_state_arrow_prompt send_state_list_display;
```

The composite events inquire_on_state_data from ROOT User and get_state_result from ROOT TT_GC_ILF contain additional behaviors which are captured in COORDINATE 1 of the MP SCHEMA for COA 3.

COA 3 COORDINATE 1 represents the interaction between the User composite event behavior inquire_on_state_data and the TT_GC_ILF composite event behavior get_state_result. The interactions of the behaviors of the composite events are represented in the nested COORDINATE, with 2 ADDs representing 2 DETs. One FTR is assumed, based on the source information. For the EI COORDINATE #12, two FTRs are referenced, but since it would not affect the functional size or complexity, it was represented in the model as 1 FTR.

```
/* COORDINATE 1: Interaction between the User behaviors and TT/Golfcourses ILF behaviors , and nested
COORDINATE with 2 ADDs representing 2 DETs */

COORDINATE $a:inquire_on_state_data              FROM User,
                $b:get_state_result                      FROM TT_GC_ILF

DO
                COORDINATE

                $ax: click_state_arrow_dropdown  FROM $a,
                $bx: receive_state_arrow_prompt  FROM $b,
                $axx: receive_state_list_display         FROM $a,
                $bxx: send_state_list_display            FROM $b
        DO

                ADD $ax PRECEDES $bx;
                ADD $bxx PRECEDES $axx;
        OD;
OD;
```

The two ADDs in COORDINATE 1 represent two DETs. The MP schema for COA 3 contains 20 COORDINATEs each with a functional complexity and size determined by the number of ADDs representing DETs. 1 FTR is used for the DETs associated with each COORDINATE.

As in COAs 1 and 2, the data functions for COA 3 are represented by SHARE ALL with an average functional complexity and size. The complete MP model for COA 3 is described in Appendix C Section 3.

The MP schema for COA 4 is named SCHEMA It Is Tee Time Nested COORDINATEs For transactional and data Functions. COA 4 leverages all the detailed source information from It's Tee Time, to represent the additional behaviors internal to each transactional function and data function, in the form of each DET in a nested COORDINATE. Since sufficient information is available to determine the actual functional complexity and size, it is not necessary to assume an average functional complexity and size for transactional functions or data functions.

The methodology used in COA 1 and 2 and 3 to create the MP schema is used as a starting point in COA 4. The behaviors of the ROOTs continue to be described using specific words associated with transactional functions EI, EO, EQ. The descriptions take advantage of composite events in the ROOTs and the additional behaviors of DETs. Each DET is represented as an ADD within the nested COORDINATE of a transactional function.

COA 4: For COA 4, the same approach used for transactional function types is applied to the data function types, using additional descriptive terms to describe the data function types. COA 4 contains COORDINATEs 21–24, representing the data functions.

For example, ROOT TT represents the relevant behaviors of the IAA, including the composite event "request". ROOT GC_ILF represents the relevant behaviors of the Golfcourses ILF including the composite event "respond."

COORDINATE 21 represents the interaction between the TT IAA and the GC_ILF, and is a nested COORDINATE with 11 ADDs representing 11 DETs.

```
ROOT TT: ( * (request | no_action ) * );

        request: request_GC_id              request_GC_coursename  request_GC_address
        request_GC_city             request_GC_state          request_GC_zip
        request_GC_phone            request_GC_description    request_GC_slope
        request_GC_fees             request_GC_requirements
        request_TT_id               request_TT_coursename   request_TT_date_repeating
        request_TT_teetime          request_TT_no_players
        request_TT_no_holes                 request_TT_golfer_name  request_TT_credit_card_type
        request_TT_credit_card_number   request_TT_phone_number

        request_scoreboard_golfer_name          request_scoreboard_coursename
        request_scoreboard_date             request_scoreboard_slope
        request_scoreboard_score            request_Merch_product_name
        request_Merch_price                 request_Merch_picture;


ROOT GC_ILF: (*( respond | no_action)*);

respond: respond_GC_id  respond_GC_coursename            respond_GC_address
respond_GC_city             respond_GC_state          respond_GC_zip                  respond_GC_phone
        respond_GC_description              respond_GC_slope                        respond_GC_fees
        respond_GC_requirements;


/* COORDINATE 21: Interaction between the TT IAA and the Golf Courses ILF, and nested COORDINATE
with 11 ADDs representing 11 DETs */


COORDINATE              $oo: request                        FROM TT,
                        $pp: respond                        FROM GC_ILF

DO

        COORDINATE

                $oox1: request_GC_id                        FROM $oo,
                $ppx1: respond_GC_id                        FROM $pp,
                $oox2: request_GC_coursename                FROM $oo,
                $ppx2: respond_GC_coursename                FROM $pp,
                $oox3: request_GC_address                   FROM $oo,
                $ppx3: respond_GC_address                   FROM $pp,
                $oox4: request_GC_city                      FROM $oo,
                $ppx4: respond_GC_city                      FROM $pp,
                $oox5: request_GC_state                     FROM $oo,
                $ppx5: respond_GC_state                     FROM $pp,
                $oox6: request_GC_zip                       FROM $oo,
                $ppx6: respond_GC_zip                       FROM $pp,
                $oox7: request_GC_phone                     FROM $oo,
                $ppx7: respond_GC_phone                     FROM $pp,
                $oox8: request_GC_description               FROM $oo,
```

```
        $ppx8: respond_GC_description          FROM $pp,
        $oox9: request_GC_slope                FROM $oo,
        $ppx9: respond_GC_slope                FROM $pp,
        $oox10: request_GC_fees                FROM $oo,
        $ppx10: respond_GC_fees                FROM $pp,
        $oox11: request_GC_requirements        FROM $oo,
        $ppx11: respond_GC_requirements        FROM $pp

    DO
        ADD $oox1 PRECEDES $ppx1;
        ADD $oox2 PRECEDES $ppx2;
        ADD $oox3 PRECEDES $ppx3;
        ADD $oox4 PRECEDES $ppx4;
        ADD $oox5 PRECEDES $ppx5;
        ADD $oox6 PRECEDES $ppx6;
        ADD $oox7 PRECEDES $ppx7;
        ADD $oox8 PRECEDES $ppx8;
        ADD $oox9 PRECEDES $ppx9;
        ADD $oox10 PRECEDES $ppx10;
        ADD $oox11 PRECEDES $ppx11;

    OD;
OD;
```

The complete MP schema for COA 4 can be found in Appendix C, section 4. Due to the size of the MP schemas for COA 3 and COA 4, the strategy to execute the model was modified, without compromising the integrity of the model or the UFP counts associated with them.

In order to run the model on Firebird, the model had to be broken into several parts. This does not affect the UFP count, but does allow the execution of the model in order to obtain event traces, which inform test case estimates. The MP model was split into two separate models; one to address the data function types, and the other to address the transactional function types.

The original MP models for COA 3 and COA 4 had a set of roots TT_xxx and a set of roots without TT prefix. Since these two sets did not interact, running them together on Firebird significantly increased the time to execute them because all possible combinations had to be produced. Running them together did not provide any additional value; as a result, they were run separately, so that event traces could be produced and inspected.

As mentioned earlier, this was done to execute the models on Firebird, however the UFP captured in the model is unaffected.

The .wng files, containing the MP schema and event traces, for Tee Time will be available on the Monterey Phoenix wiki hosted by the Naval Post Graduate School [47].

(4) Step 4: Extract Data Functions count from MP model

COA 1: By manually inspecting the MP schema in Appendix C Section 1, a total of 4 SHARE ALLs can be extracted from the model.

COA 2: By manually inspecting the MP schema in Appendix C Section 2, a total of 4 SHARE ALLs can be extracted from the model. By inspecting the model for ILFs and EIFs associated with the SHARE ALLs, 3 ILFs and 1 EIF are extracted for data functions.

COA 3: By manually inspecting the MP schema in Appendix C Section 3, a total of 4 SHARE ALLs can be extracted from the model. By inspecting the model for ILFs and EIFs associated with the SHARE ALLs, 3 ILFs and 1 EIF are extracted for data functions.

COA 4: By manually inspecting the MP schema in Appendix C Section 4, a total of 4 COORDINATEs can be extracted from the model for data function types. By inspecting the model for ILFs and EIFs associated with the COORDINATEs, 3 ILFs and 1 EIF are extracted for data functions.

(5) Step 5: Extract Transactional Functions count from MP model

COA 1: By manually inspecting the MP schema in Appendix C Section 1, a total of 20 COORDINATEs representing transactional functions can be extracted from the model.

COA 2: By manually inspecting the MP schema in Appendix C Section 2, a total of 20 COORDINATEs representing transactional functions can be extracted from the model. The transactional functions can be distinguished by inspecting the model for specific words used to describe the behaviors associated with each COORDINATE. For

example, words like “inquire” or “view” are associated with an for EQ; “add”, “change”, or “delete” for an EI; and “calculate” or “buy” for an EO.

COA 3: By manually inspecting the MP schema in Appendix C Section 3, a total of 20 COORDINATEs representing transactional functions can be extracted from the model. The transactional functions can be distinguished by inspecting the model for specific words used to describe the behaviors associated with each COORDINATE. For example, words like “inquire” or “view” are associated with an for EQ; “add”, “change”, or “delete” for an EI; and “calculate” or “buy” for an EO.

COA 4: By manually inspecting the MP schema in Appendix C Section 4, a total of 20 COORDINATEs representing transactional functions can be extracted from the model. The transactional functions can be distinguished by inspecting the model for specific words used to describe the behaviors associated with each COORDINATE. For example, words like “inquire” or “view” are associated with an for EQ; “add”, “change”, or “delete” for an EI; and “calculate” or “buy” for an EO.

(6) Step 6: Extract integration test cases and views from MP model

Extracting event traces (i.e. use cases) from an MP schema sets the conditions to verify the model either through manual inspection of the event traces or by leveraging automated tools. The use cases serve as a valuable blueprint for the construction of integration test cases, which can then be used to support integration test estimates.

For COA 1, Scope 1 was used and considered sufficient. The event traces were inspected and increasing the scope did not show anything new or notable, and would not improve chances of exposing errors in testing.

Utilizing the MP analyzer tool on Firebird and Scope 1, 864 Event Traces were generated. Recall that a test case includes test steps, preconditions, test data that supports what the test case needs to achieve, expected results, post conditions, and information about the environment.

The event traces generated from an MP model provide solid detailed blueprints, which can be viewed as guidelines for the creation of the integration test cases. Three examples of the 864 event traces are illustrated in Figures 40–42.

Figure 40 represents event trace #1 of 864. While early on in the execution of the model, is still has detail describing the behaviors of the Tee Time application.

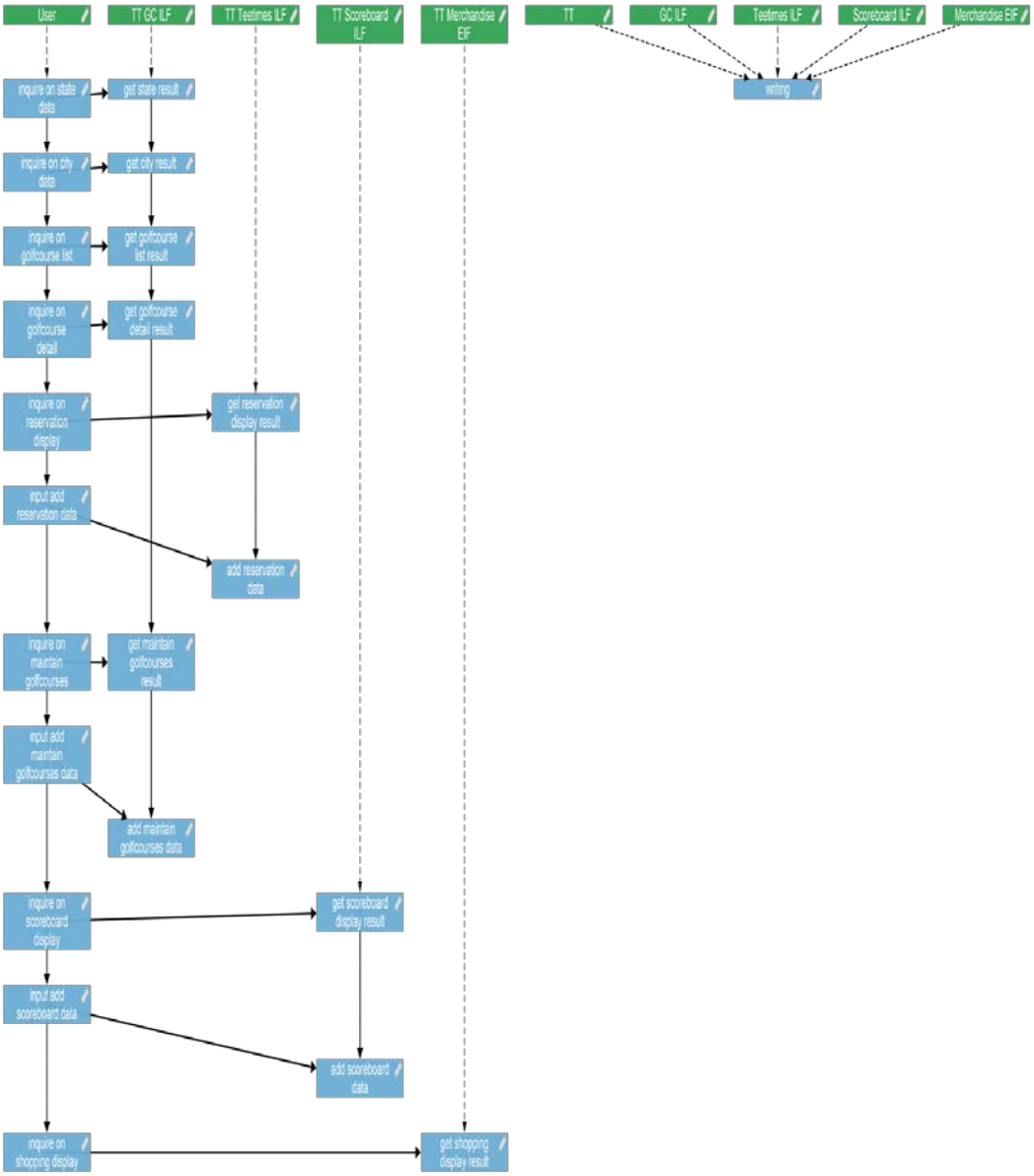


Figure 40. Event Trace #1 of 864

Figure 41 represents event trace #400 of 864. The event trace begins to reflect the complexity of the behaviors.

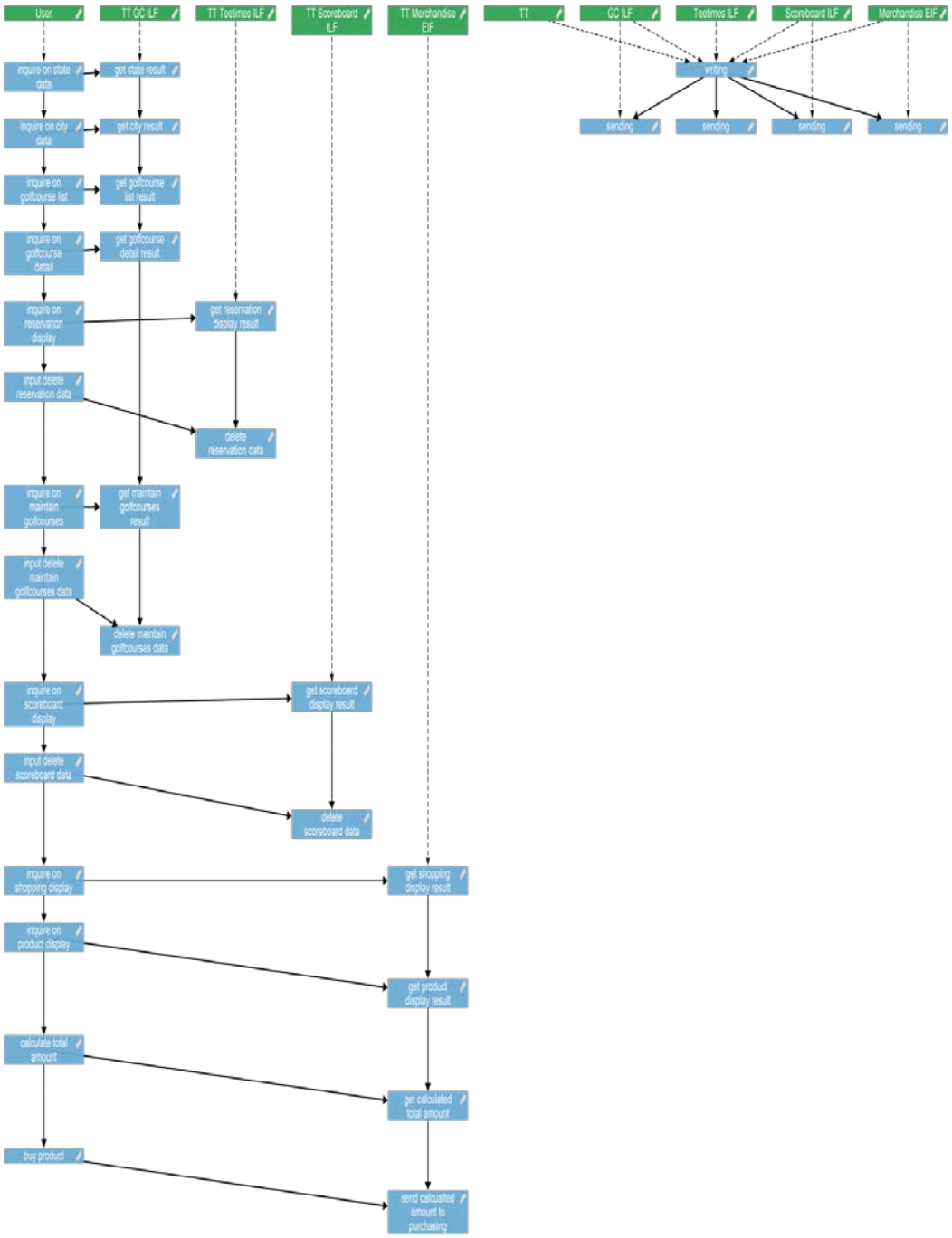


Figure 41. Event Trace #400 of 864

Figure 42 represents event trace #864 of 864. The event trace represents additional behaviors and additional complexity.

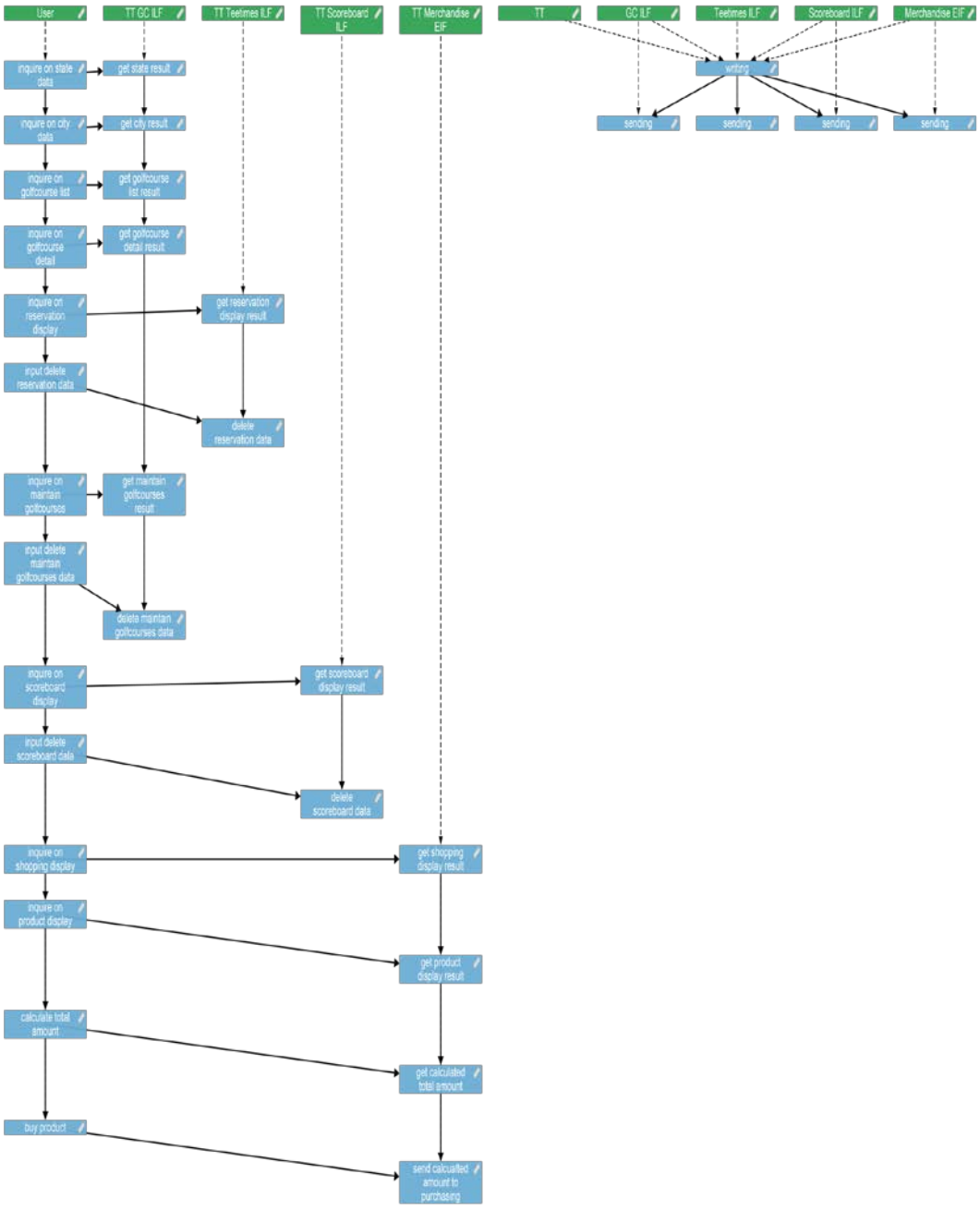


Figure 42. Event Trace #864 of 864

Recall Brooks stated “successfully used the following rule of thumb for scheduling a software task: 1/3 planning, 1/6 coding, 1/4 component test and early system test, 1/4 system test, all components in hand” [53, p. 20].

.25 x Total effort = Estimate for integration testing

As discussed by Wolff, approximately six integration tests per day can be executed for a large application, such as an electronic commerce system [58, p. 16]. This does not include the amount of time required to create the test case.

In the COCOMO II results that will be discussed in Step 8, the Integration and Test costs are part of the phase effort for Construction. In this phase breakdown the total Construction is 76% of the software development effort. Using the waterfall lifecycle definitions for COCOMO II the breakdown is: Product Design 17%; Programming 58%; Integration and Test 25% [55].

As is illustrated in Figure 44 for COA 1, the Construction phase is allocated 6.4 months of schedule. Twenty-five percent of that time is 1.6 months, which corresponds to 32 days (assuming five days per week and eight hours per day for each staff person). Assuming that six test cases per day can be executed, then 192 test cases can be executed in the allocated time for test and integration.

However, there are 864 event traces generated in the MP model for COA 1. Not including the time required to create the actual test cases, this would require over 144 days to execute all testing. Upon inspection of the event traces, some are significantly less complicated than others, so test case generation and execution based on each event trace will not require the same amount of effort. But this does provide information for next steps to inform decision making, both technically and programmatically. The first step is to revisit the model, and ensure that the behaviors of the application are accurately captured. If the model is correct, then the next step is to determine is there any flexibility in the schedule and resources to support additional testing. Since 144 days is unrealistic, it becomes clear that only a subset of event traces can be selected for testing.

If schedule does not support 192 test cases, then the event traces will need to be inspected and a subset selected for use in the creation of test cases. Which ones to select is a topic for future work.

(7) Step 7: Determine the Unadjusted Function Point (UFP) count

COA 1: For this COA, limited source information was applied so average functional complexity and size values were used.

By assuming an EI/EO/EQ average functional complexity and size values, derived from the IFPUG tables for transactional functions, the average value is (4+5+4)/3 = 4.3 For the 20 transactional functions, represented by COORDINATEs, the resulting UFP count is 20 x 4.3 = 86 UFP.

By assuming an ILF/EIF average functional complexity and size value, derived from the IFPUG tables for data functions, the average value is (10 +7)/2= 8.5. For the four data functions, represented by SHARE ALLs, the resulting UFP count is (4 x 8.5) = 34 UFP.

The total UFP count provided in the It's Tee Time source data is 88 UFP. Using the ThreeMetrics methodology, the total UFP for COA 1 is 120 UFPs, which results in a delta of 32 UFPs.

COA 2: By inspecting the model for key words associated with the behaviors of each COORDINATE composition operation, the values for average for EI (4), average for EO (5), and average for EQ (4) can be used to calculate the transactional function UFP total.

(9 "inquire" COORDINATEs x 4 UFP/COORDINATE) + (2 "calculate or buy" COORDINATEs x 5 UFP/COORDINATE) + (9 "add, change, delete" COORDINATEs x 4 UFP/COORDINATE) = 36 + 36 + 10 = 82 UFP

Using ILF average functional size of 10, and the EIF average functional size of 7, (3 ILF SHARE Alls x 10) + (1 EIF SHARE Alls x 7) = 37.

The number of UFPs calculated for COA 2 is 82 + 37 = 119 UFPs.

The total UFP count provided in the It's Tee Time source data is 88 UFP. The total UFP for COA 2, using the ThreeMetrics methodology and assuming an average functional complexity and size is 119 UFPs, a delta of 31 UFPs from the source information.

COA 3: By inspecting the model for key words associated with the behaviors of each COORDINATE composition operation, and the number of ADDs (representing DETs) within each COORDINATE, the values for nine EIs, nine EQs, and two EOs, to calculate the transactional function UFP count. Tables 18, 19, and 20 illustrate the UFP count for transactional function types, extracted from the MP model for COA 3. Each COORDINATE is numbered and has a corresponding functional complexity and size, based on the number of ADDs (i.e., DETs) associated with each COORDINATE. Additionally, the MP schema can be mined for specific words, e.g. inquire, add, change, calculate, to specify what type of transactional function the COORDINATE is representing.

Table 18 addresses the list of EQ COORDINATEs that were extracted from the MP schema for COA 3.

Table 18. EQ COORDINATEs Extracted From MP Schema for COA 3

EP	Description	ILF/EIF	FTR/DET	MP Schema COA 3 COORDINATE #	Complexity	UFP
EQ	State Drop Down	Golf Courses (I)	(1,2)	1	Low	3
EQ	City Drop Down	Golf Courses (I)	(1,3)	2	Low	3
EQ	Golf Course List	Golf Courses (I)	(1,4)	3	Low	3
EQ	Golf Course Detail	Golf Courses (I)	(1,12)	4	Low	3
EQ	Scoreboard Display	Scoreboard (I)	(1,6)	13	Low	3
EQ	Maintain Golf Course Display (by ID)	Golf Courses (I)	(1,13)	9	Low	3
EQ	Tee Times Reservation Display	Tee Times (I)	(1,11)	5	Low	3
EQ	Tee Times Shopping Product Display	Merchandise (E)	(1,3)	17	Low	3
EQ	Product View Picture	Merchandise (E)	(1,3)	18	Low	3

Table 19 addresses the list of EI COORDINATEs that were extracted from the MP schema for COA 3.

Table 19. EI COORDINATEs Extracted From MP Schema for COA 3

EP	Description	ILF/EIF	FTR/DET	MP Schema COA 3 COORDINATE #	Complexity	UFP
EI	Scoreboard (ADD)	Scoreboard (I)	(1,7)	14	Low	3
EI	Scoreboard (CHANGE)	Scoreboard (I)	(1,7)	15	Low	3
EI	Scoreboard (DELETE)	Scoreboard (I)	(1,3)	16	Low	3
EI	Maintain Golf Course (ADD)	Golf Courses (I)	(1,13)	10	Low	3
EI	Maintain Golf Course (CHANGE)	Golf Courses (I)	(1,13)	11	Low	3
EI	Maintain Golf Course (DELETE)	Golf Courses (I) Tee Times	(2,3)	12	Low	3
EI	Tee Times Reservations (ADD)	Tee Times (I)	(1,12)	6	Low	3
EI	Tee Times Reservations (CHANGE)	Tee Times (I)	(1,12)	7	Low	3
EI	Tee Times Reservations (DELETE)	Tee Times (I)	(1,6)	8	Low	3

Table 20 addresses the list of EO COORDINATEs that were extracted from the MP schema for COA 3.

Table 20. EO COORDINATEs Extracted From MP Schema for COA 3

EP	Description	ILF/EIF	FTR/DET	MP Schema COA 3 COORDINATE #	Complexity	UFP
EO	Shopping Display (Calculation)	Merchandise	(1,7)	19	Low	4
EO	Buy – Send to Purchasing (Calculation)	Merchandise	(1,15)	20	Low	4

Adding the individually calculated UFP counts of the EQ, EI, and EO transactional functions result in 62 UFPs for the transactional functions.

Assuming an average functional complexity and size for the data functions, and inspecting the model for ILFs and EIFs, the UFP for data functions is

(3 ILF SHARE ALLs x 10 UFP/SHARE ALL) + (1 EIF SHARE ALL x 7 UFP/SHARE ALL) = 37 UFPs

The total UFP for COA 3 is 62 UFP + 37 UFP = 99 UFP. The source information indicated that the UFP for the It's Tee Time Example is 88 UFP, indicating that there is a delta of 11 UFP between the COA 3 count and the source information.

COA 4: By inspecting the model for key words associated with the behaviors of each COORDINATE composition operation, and the number of ADDs (representing DETs) within each COORDINATE, the values of the EIs, EOs, and EQs are calculated to determine the total transactional function UFP count. Tables 20, 21, and 22 illustrate the UFP count for transactional function types, extracted from the MP model for COA 3, that is still applicable to COA 4. Each numbered nested COORDINATE has a corresponding functional complexity and size, based on the number of ADDs (i.e., DETs) associated with each COORDINATE. Additionally, the MP schema can be mined for specific words, e.g. inquire, add, change, calculate, to specify what type of transactional function the COORDINATE is representing.

As discussed earlier, for COA 4, the behaviors of each ROOT are captured by specific activities associated with each ROOT, based on the requirements, supporting information, and the ThreeMetrics box and arrow representation.

COA 4 leverages the rich source information provided in the It's Tee Time example to represent behaviors of the DETs in a nested COORDINATE for transactional functions. Each ADD within the nested COORDINATE of a transactional function represents a DET.

Additionally, for COA 4, the interactions between the IAA and the ILFs and EIF are captured by representing the DETs in a nested COORDINATE for data functions. Each ADD within the nested COORDINATE of a data function represents a DET. Based on the source information provided, each ILF and EIF has one RET.

Table 21 illustrates the UFP count for data functions, extracted from the MP model for COA 4. Each numbered nested COORDINATE has a corresponding functional complexity and size, based on the number of ADDs (i.e., Data Element Types) associated with each COORDINATE. Additionally, the MP Schema can be mined for specific words, e.g. ILF and EIF, to specify what type of file the COORDINATE is representing.

Table 21. Data Function UFP Using Nested COORDINATE

Description	ILF/EIF	RET/DET	MP Schema COA 4 COORDINATE #	Complexity	UFP
Golf Course	ILF	(1,11)	21	Low	7
Tee Times	ILF	(1,10)	22	Low	7
Scoreboard	ILF	(1,5)	23	Low	7
Merchandise	EIF	(1,3)	24	Low	5

(1 ILF x 7UFP/ILF) + (1 ILF x 7UFP/ILF) + (1 ILF x 7UFP/ILF) + (1 EIF x 5 UFP/EIF) = 26 UFPs

Recall that adding the individually calculated UFP counts of the EQ, EI, and EO transactional functions result in 62 UFPs for the transactional functions. The UFP counts from Tables 21, 22 and 23, when added to Table 24 result in

62 UFPs + 26 UFP = 88 UFP

The total UFP for COA 4 is 88 UFPs. The source information indicated that the UFP count for the It's Tee Time Example is 88 UFPs, the same as COA 4.

(8) Step 8: Calculate effort estimate

The calculation for COA 1 is included in this example. Using the total UFP count of 120 UFPs for COA 1 and directly inputting into [57], for a JAVA implementation language, Maintenance Off and a Cost per Person-Month of $20,000, results in the nominal estimates synopsized in Table 22 and supported by Figures 43 and 44.

Table 22. Nominal Effort Estimates for COA 1

Option	Effort	Schedule	Cost	Language	Total Equivalent Size
Nominal Effort Options Selected, Maintenance Off	22.5 Person-months	10.3 months	$449,716	Java	6360 SLOC

Figure 43 illustrates the options available in the COCOMO II model. For this analysis, nominal inputs were selected with 120 UFPs manually inserted into the model.

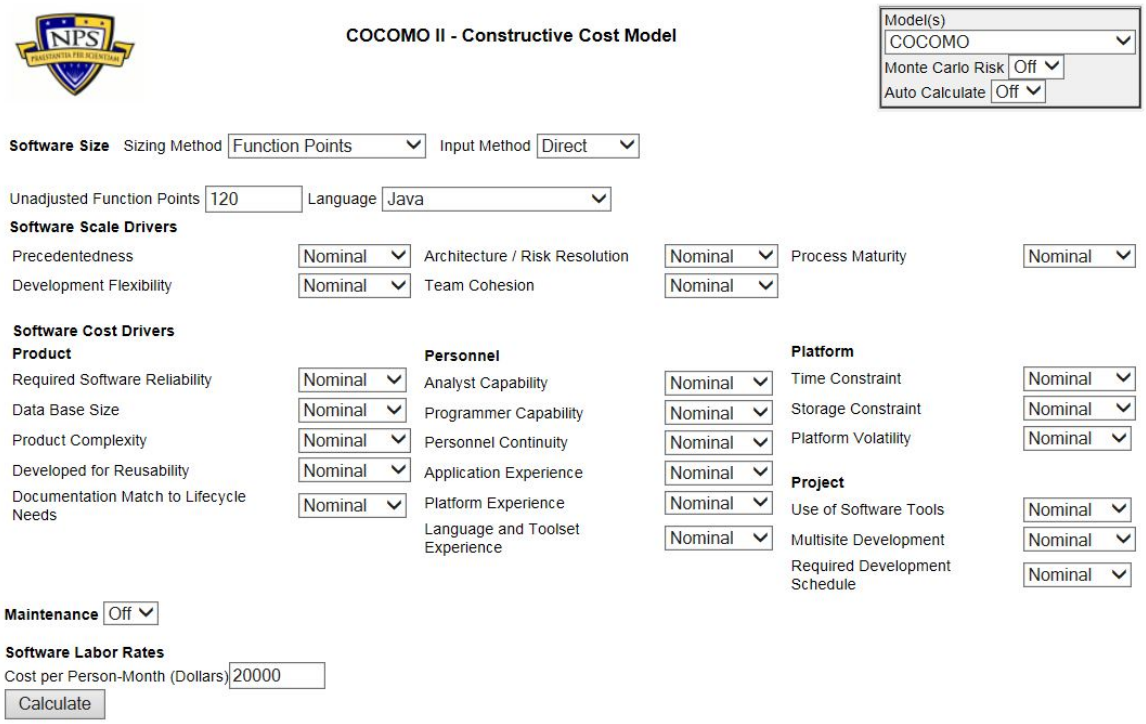


Figure 43. Nominal Effort Options Selected for COA 1, Maintenance Off

Figure 44 illustrates the results of the COCOMO II model for 120 UFPs manually inserted into the model.

Results

Software Development (Elaboration and Construction)

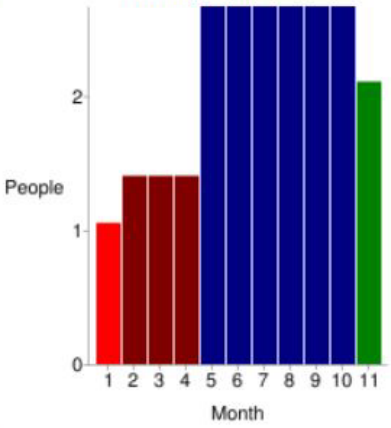
Effort = 22.5 Person-months
Schedule = 10.3 Months
Cost = $449716

Total Equivalent Size = 6360 SLOC

Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	1.3	1.3	1.1	$26983
Elaboration	5.4	3.8	1.4	$107932
Construction	17.1	6.4	2.7	$341785
Transition	2.7	1.3	2.1	$53966

Staffing Profile



Software Effort Distribution for RUP/MBASE (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	0.2	0.6	1.7	0.4
Environment/CM	0.1	0.4	0.9	0.1
Requirements	0.5	1.0	1.4	0.1
Design	0.3	1.9	2.7	0.1
Implementation	0.1	0.7	5.8	0.5
Assessment	0.1	0.5	4.1	0.6
Deployment	0.0	0.2	0.5	0.8

Your output file is http://csse.usc.edu/tools/MP_COCOMO/data/COCOMO_June_26_2016_19_35_22_260329.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

Figure 44. Nominal Effort Options for COA 1, Maintenance Off, Results

The same methodology used to calculate the effort estimate for COA 1 is applicable to COAs 2–4. The COCOMO II outputs for COAs 1–4, are illustrated in Table 23.

Table 23. COCOMO II Output

Total UFP Count	Effort (Person-months)	Schedule (Months)	Cost (Dollars)	SLOC
120	22.5	10.3	449,716	6360
119	22.3	10.2	445,597	6307
99	9.6	9.6	363,968	5247
88	9.2	9.2	319,750	4664

(9) Step 9: Finalize analysis and provide results to stakeholders

As discussed earlier, each stakeholder is interested in a slightly different view of the same set of information. However, these views must be consistent with each other, accurately representing a subset of the whole set of information.

Each step of the ThreeMetrics methodology provides meaningful information to stakeholders. Programmers and engineers will appreciate the high-level pseudo code of the MP model in Appendix C, since it describes the behaviors of the Tee Time application and its internal and external interactions. System and software engineers will appreciate the box and arrow format of the information in Figure 39. Cost analysts and program managers will appreciate the results of the COCOMO II model in Figure 44, as input to resourcing requirements presented with each instance of the architecture model. Testers will appreciate the use cases (event traces) in Figures 40–42, and the sequence diagrams view that inform integration test case creation.

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V. SUMMARY OF RESULTS AND FINDINGS

The initial goal of this research was to answer the question "Can unadjusted function point counts be extracted from executable architectural behavioral models, for use in cost estimation models such as COCOMO II, in order to inform effort estimates early in the life cycle?"

ThreeMetrics methodology, and its application to the examples in Chapter IV, confirm the following contributions of this work:

- The ThreeMetrics methodology does relate function point counting, COCOMO II cost estimates, and executable behavioral modeling of system and software architecture specifications.
- The ThreeMetrics methodology, based on MP architecture model, provides a way of establishing internal and external boundaries for function point counting.
- The use of the MP language and framework significantly simplified otherwise complex relationships. The ability to execute the model using MP Analyzer on Firebird, inspect it, and debug it, provided confidence in the results of the model.
- The ThreeMetrics methodology successfully unifies the two distinct function point counting concepts of data function types and transactional function types.

A. RESULTS AND FINDINGS

This research introduced a newly developed methodology called the ThreeMetrics, whose name represents the three metrics resulting from the methodology: UFP counts, use cases to inform integration test estimates, and views of the architecture.

The ThreeMetrics methodology employed architecture modeling of the behaviors of a software-intensive system, the behaviors of the environment, and the behaviors of the system interacting with the environment, in order to inform technical and investment decisions. This research accomplished the following:

- As described in Chapter III, this research presented a nine-step methodology to extract an UFP count from MP's executable architecture models for use in software cost estimation.

- As demonstrated in three examples in Chapter IV, the ThreeMetrics methodology leveraged precise behavioral modeling using MP and the MP Analyzer on Firebird to assess architecture design decisions and their impacts.

- As demonstrated in three examples in Chapter IV, the ThreeMetrics methodology related architecture modeling to resourcing through analysis of behaviors and UFP counts, leveraging complexity and size metrics such as DETs. The COCOMO II model extension was used to manually input the UFP count (extracted from the MP model) into the COCOMO II model, to determine cost estimates.

- As demonstrated in three examples in Chapter IV, the ThreeMetrics methodology used event traces (i.e. use cases) to inform integration testing estimates and decision making, based on estimates extracted from the Construction phase of the COCOMO II model.

- As demonstrated in three examples in Chapter IV, the ThreeMetrics methodology leveraged aspects of the FP counting methodology to write the MP model with key words to distinguish between EI, EO, and EQ transactional function types improved the accuracy of the UFP count.

- As demonstrated in the four COAs of example three in Chapter IV, accurately representing the data function interactions contributed to an accurate total UFP count.

- As demonstrated in three examples in Chapter IV, each step in the ThreeMetrics methodology contributed to information, consistently represented in multiple views and formats, that can be used communicate with multiple stakeholders.

The UFP results of the three examples explored in Chapter IV are summarized in Table 24. The UFPs extracted from the model approached the UFP count from the source info answer key, as more details associated with the ILF and EIF were used. Representing the behaviors of the data function types was accomplished using the IAA and capturing the interactions between the data functions and the IAA in the MP model.

Table 24. UFP Summation for Examples in Chapter IV

Example Name	Representation of Data Function Types in MP	Total # Data Function Type UFP	Representation of Transactional Function Type in MP	Total # Transactional Function Type UFP	ThreeMetrics Total UFP Count	Source Info Total Key UFP Count
Spell Checker	SHARE ALL	24	COORDINATE	31	55	58
Course Marks	SHARE ALL	15	COORDINATE	24	39	35 or 34
It's Tee Time						
- COA 1	SHARE ALL	34	COORDINATE	86	120	88
- COA 2	SHARE ALL with ILF and EIF keywords	37	COORDINATE with EI, EO, EQ keywords	82	119	88
- COA 3	SHARE ALL with ILF and EIF keywords	37	Nested COORDINATE and ADD, with EI, EO, EQ keywords	62	99	88
- COA 4	COORDINATE with ILF and EIF keywords	26	Nested COORDINATE and ADD, with EI, EO, EQ keywords	62	88	88

B. CONCLUSIONS

The ThreeMetrics methodology does relate architecture modeling to resourcing through UFP counts, and has demonstrated that an UFP count can be extracted from an MP executable architecture model, for use in software cost estimation.

The ThreeMetrics methodology leverages precise behavioral modeling using MP and the MP Analyzer on Firebird to assess architecture design decisions and their impacts. UFP counts can be manually inserted into the COCOMO II tool determine cost estimates.

The ThreeMetrics methodology uses event traces and schedule information from the COCOMO II model, to inform integration test estimates and decision making.

Each step of the ThreeMetrics methodology provides meaningful information to stakeholders in the form of precise models, pseudo code, box and arrow diagrams, event traces and cost estimates.

C. FUTURE WORK

This research sets the conditions for interesting future work, building upon the foundation of the ThreeMetrics methodology. Several topics are included below.

Although event traces were used to inform estimates for integration test cases, the process and the criteria for the selection of a subset of relevant event traces to inform integration test cases has not yet been done. Resourcing and schedule constraints may limit the number of test cases that can be created from the set of MP event traces.

Currently, the UFP count extracted from the MP model is manually entered into the COCOMO II model. A current prototype has demonstrated that a .mp file can uploaded and parsed to extract the UFP count from the MP model. A future implementation is required to automate the process to extract an UFP from a .mp file, using the rules identified in the ThreeMetrics methodology.

The ThreeMetrics methodology must continue to be evaluated in the broader context of the COCOMO II model. How MP metrics relate to the evaluation of actual projects must be explored to demonstrate actual value, improve the mechanics of the evaluation process, and establish new perspectives on COCOMO II and MP.

An MP model is a rich source of information, but not all the information in an MP model, particularly the event grammar (i.e., pseudo code) has been utilized in this research. Cost estimates derived from early architecture models need to take advantage of all information available in the MP model. Besides using FPA, there are other complexity and size metrics that can be employed. For example, consider that

Cost = K1*FP_metrics + K2*Complexity_metrics + K3*Size_estimate

FP counts are calculated mostly following the established FP methodology, identifying the MP interactions and assigning functional complexity and size values. Complexity metrics can also address alternatives and iterations in the MP model that clearly indicate that an effort will be needed to implement them. Size estimates should then consider the total number of events, composite events, roots, alternatives, iterations,

concurrent events. Additional consideration must be given to how to properly balance these metrics, such as determining what other information from the MP model may be of use (such as reuse metrics), and considering how K1, K2, K3 coefficients should be obtained, perhaps based on heuristics.

The IFPUG is continuing to evolve the Software Non-functional Assessment Process (SNAP) counting practice which “measures software by quantifying the size of non-functional requirements” [70]. An MP model can be refined to include greater levels of detail about the application, if that detail is available. This includes further decomposition of functional requirements and then linking them to technical (or non-functional) requirements. Since SNAP focuses on the non-functional requirements, the role of MP, the ThreeMetrics methodology, and SNAP is another topic for future work.

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APPENDIX A. MP SCHEMA FOR SPELL CHECKER

```
/*      Name: MP SCHEMA Spellchecker
        Purpose: Spelling Checker example for UFP estimate, derived from N. Fenton, J. Bieman,
        Software Metrics, 3rd Edition, CRC, 2015, pp.252-254 [69].
        Authors: This example was refined and improvised by M. Auguston on 02/08/16 and Monica
        Farah-Stapleton on 02/16/16
        Tool Used: MP Analyzed on Firebird
        Scope: 1            */


SCHEMA Spellchecker

ROOT User: (*   provide_document_file_name
                    [ provide_personal_dictionary ]
                    [inquire_on_number_of_processed_words]
                    [ check_number_of_processed_words ]
                    [inquire_on_number_of_errors_so_far]
                    [ check_number_of_errors_so_far ]
                    read_spelling_report
                    update_document_file
                    read_errors_message
                    [ update_personal_dictionary ]
                    [receive_misspld_wrd_rpt]
               *)
                    no_more_errors
                    end_of_work;



ROOT Spell_chk : (*     read_document_file
                        Process_document
                    [send_number_of_processed_words]
                        [ report_number_of_processed_words ]
                    [send_number_of_errors]
                        [ report_number_of_errors ]
                        provide_spelling_report
                        [report_misspld_wrd]
                        *) ;

                    Process_document:       read_dictionary
                                            [ read_personal_dictionary ]
                                            [ spelling_errors_detected ]
                                            ;

/* EI: Doc_filename */

COORDINATE          $pdoc: provide_document_file_name FROM User,
                    $rdoc: read_document_file                 FROM Spell_chk
        DO          ADD $pdoc PRECEDES $rdoc; OD;
```

```
/* EI: Pers_diction_file */

COORDINATE          $p1: provide_personal_dictionary FROM User,
                    $r1: read_personal_dictionary    FROM Spell_chk
        DO          ADD $p1 PRECEDES $r1; OD;


/* EQ: Inquire_errors_so_far */

COORDINATE  $cnerr: inquire_on_number_of_errors_so_far FROM User,
            $rnerr: send_number_of_errors              FROM Spell_chk
        DO  ADD $rnerr PRECEDES $cnerr;    OD;


/* EO: No_ers_so_far_msg */

COORDINATE  $cnerr1: check_number_of_errors_so_far FROM User,
            $rnerr1: report_number_of_errors  FROM Spell_chk
        DO  ADD $rnerr1 PRECEDES $cnerr1;
        OD;


/* EQ: Inquire_words_processed*/

COORDINATE  $cwn: inquire_on_number_of_processed_words  FROM User,
            $rwn: send_number_of_processed_words        FROM Spell_chk
        DO  ADD $rwn PRECEDES $cwn;
        OD;


/* EO: No_wrds_prosd_msg */

COORDINATE  $cwn1: check_number_of_processed_words      FROM User,
            $rwn1: report_number_of_processed_words     FROM Spell_chk
        DO  ADD $rwn1 PRECEDES $cwn1;
        OD;



/* EO: Misspld_wrd_rpt */

COORDINATE  $cwn2: receive_misspld_wrd_rpt  FROM User,
            $rwn2: report_misspld_wrd               FROM Spell_chk
        DO  ADD $cwn2 PRECEDES $rwn2;
        OD;
```

```
ROOT Dictionary: (* read_dictionary *);

ROOT Document_file:          (*      (* read_document_file *)
                                     (* update_document_file *)
                                     (* send_document_file *)
                             *);

ROOT Personal_Dictionary:    (*      (* update_personal_dictionary      *)
                                     (* read_personal_dictionary        *)
                             *);

Spell_chk, Dictionary                        SHARE ALL read_dictionary;

Spell_chk, Personal_Dictionary               SHARE ALL read_personal_dictionary ;

Spell_chk, Document_file                SHARE ALL update_document_file;
```

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APPENDIX B. MP SCHEMA FOR COURSE MARKS

```
/*      Name: MP SCHEMA Course Marks
        Purpose: The Course Marks System example for UFP estimate is derived from  N.Fenton,
        J.Bieman, Software Metrics, 3rd Edition, CRC, 2015, pp. 367-368 and 546-548 [69]. This example
        was refined and improvised by Monica Farah-Stapleton 03/02/16, and MP Schema updated by
        Prof Mikhail Auguston, 03/02/16.
        Tool Used: MP Analyzed on Firebird
        Scope: 3            */

        SCHEMA Course Marks

        ROOT User: (* select_course_choice

                                select_operation_choice

                                (enter_coursework_marks | modify_coursework_marks)

                                (enter_exam_marks | modify_exam_marks)

                                inquire_on_average_grade

                                inquire_on_letter_grade

                                receive_student_marks_report

                        *)

                                end_of_activity;



        ROOT Grade_collector: (* return_course_selection

                                        return_operation_selection

                                        receive_coursework_marks_input

                                        receive_exam_marks_input

                                        calculate_average_grade
```

```
                    write_average_grade
                    send_average_grade
                    equate_average_grade_to_letter
                    send_letter_grade
                    create_student_marks_report
                    send_student_marks_report

                *) ;



/* EI: Menu_selct_course_choice */
COORDINATE    $pdoc: select_course_choice          FROM User,
              $rdoc: return_course_selection       FROM Grade_collector
    DO        ADD $pdoc PRECEDES $rdoc; OD;



/* EI: Menu_selct_operation_choice */
COORDINATE    $p1: select_operation_choice         FROM User,
              $r1: return_operation_selection      FROM Grade_collector
    DO        ADD $p1 PRECEDES $r1; OD;



/* EI: Coursework_marks */
```

```
COORDINATE      $p1: enter_coursework_marks          FROM User,
                $r1: receive_coursework_marks_input  FROM Grade_collector
        DO      ADD $p1 PRECEDES $r1; OD;

/* EI: Exam_marks */
COORDINATE      $p1: enter_exam_marks                FROM User,
                $r1: receive_exam_marks_input        FROM Grade_collector
        DO      ADD $p1 PRECEDES $r1; OD;

/* EQ: Average */
COORDINATE      $p1: inquire_on_average_grade        FROM User,
                $r1: send_average_grade              FROM Grade_collector
        DO      ADD $p1 PRECEDES $r1; OD;

/* EQ: Letter_grade */
COORDINATE      $p1: inquire_on_letter_grade         FROM User,
                $r1: send_letter_grade               FROM Grade_collector
        DO      ADD $p1 PRECEDES $r1; OD;

/* EO: List_of_student_marks */
```

```
COORDINATE    $cnerr: receive_student_marks_report        FROM User,
              $rnerr: send_student_marks_report           FROM Grade_collector
    DO        ADD $cnerr PRECEDES $rnerr;
    OD;


ROOT Coursefile:  (*    receive_coursework_marks_input
                        receive_exam_marks_input
                        update_student_exam_mark
                        update_coursework_mark
                        write_average_grade
                   *);


Grade_collector, Coursefile    SHARE ALL    receive_exam_marks_input,
                                            write_average_grade,
                                            receive_coursework_marks_input;
```

APPENDIX C. MP SCHEMA FOR IT'S TEE TIME COAS 1–4

A. MP SCHEMA FOR COURSE OF ACTION 1

```
/*      Name: MP SCHEMA TeeTime_COA1_COA2.
        Purpose: The It's Tee Time example for UFP estimate is derived from the It's Tee Time counting
        example, courtesy of Q/P Management Group. TeeTime source information is protected by
        copyright [56]. This example was refined and improvised by Monica Farah-Stapleton 06/20/16,
        and updated by Prof Mikhail Auguston, 06/22/16.
        Tool Used: MP Analyzed on Firebird
        Scope: 1                                                    */


SCHEMA TeeTime_COA1_COA2


/* ROOT User: Behaviors executed by the User of the It's Tee Time application */

ROOT User: (* ( (inquire_on_state_data
                            inquire_on_city_data
                            inquire_on_golfcourse_list
                            (* (inquire_on_golfcourse_detail | go_back )*)
                            inquire_on_reservation_display
                            (input_add_reservation_data |
 input_change_reservation_data |
 input_delete_reservation_data)
                                    inquire_on_maintain_golfcourses
                                    (input_add_maintain_golfcourses_data |
          input_change_maintain_golfcourses_data |
 input_delete_maintain_golfcourses_data) )
                           inquire_on_scoreboard_display
                            (input_add_scoreboard_data |
 input_change_scoreboard_data |
 input_delete_scoreboard_data)
                                    inquire_on_shopping_display
                                    (* (inquire_on_product_display
 calculate_total_amount
 buy_product )*)

                                                                | exit)
                                    *);

/* ROOT TT_GC_ILF: The combined, relevant behaviors of the IAA and Golfcourses ILF */

ROOT TT_GC_ILF: (* (get_state_result
                                    get_city_result
                                    get_golfcourse_list_result
                                    get_golfcourse_detail_result
```

```
                        get_maintain_golfcourses_result
                        (*(add_maintain_golfcourses_data |
                change_maintain_golfcourses_data |
                delete_maintain_golfcourses_data)*) )


                *);


/* ROOT TT_Teetimes_ILF: The combined, relevant behaviors of the IAA and Teetimes ILF */

ROOT TT_Teetimes_ILF: ( get_reservation_display_result
                        (*(add_reservation_data
                                | change_reservation_data
                                        | delete_reservation_data)*)
                        );

/* ROOT TT_Scoreboard_ILF: The combined, relevant behaviors of the IAA and Scoreboard ILF */

ROOT TT_Scoreboard_ILF: ( get_scoreboard_display_result
                        (*(add_scoreboard_data
                                | change_scoreboard_data
                                        | delete_scoreboard_data)*)
                        );

/* ROOT TT_Merchandise_EIF: The combined, relevant behaviors of the IAA and Merchandise EIF */

ROOT TT_Merchandise_EIF: ( get_shopping_display_result
                        (*(get_product_display_result
                        get_calculated_total_amount
                        send_calculated_amount_to_purchasing)*)
                        );


/* ROOT TT: The relevant behaviors of the IAA */

ROOT TT: (* (writing | reading) *);


/* ROOT GC_ILF: The relevant behaviors of the Golfcourses ILF */

ROOT GC_ILF: (+writing +) (*sending*);


/* ROOT Teetimes_ILF: The relevant behaviors of the Teetimes ILF */

ROOT Teetimes_ILF: (+writing +) (*sending*);


/* ROOT Scoreboard_ILF: The relevant behaviors of the Teetimes ILF */
```

```
ROOT Scoreboard_ILF: (+writing +) (*sending*);

/* ROOT Merchandise_ILF: The relevant behaviors of the Merchandise EIF */

ROOT Merchandise_EIF: (+writing +) (*sending*);


/* COORDINATE 1: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE $a:inquire_on_state_data                    FROM User,
                          $b:get_state_result          FROM TT_GC_ILF

DO      ADD $a PRECEDES $b;OD;

/* COORDINATE 2: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE $c:inquire_on_city_data                     FROM User,
                   $d:get_city_result                  FROM TT_GC_ILF

DO      ADD $c PRECEDES $d;OD;

/* COORDINATE 3: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */


COORDINATE $e:inquire_on_golfcourse_list               FROM User,
                    $f:get_golfcourse_list_result      FROM TT_GC_ILF

        DO      ADD $e PRECEDES $f;OD;

/* COORDINATE 4: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE      $g:inquire_on_golfcourse_detail        FROM User,
                    $h:get_golfcourse_detail_result    FROM TT_GC_ILF

        DO      ADD $g PRECEDES $h;OD;


/* COORDINATE 5: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE      $i:inquire_on_reservation_display      FROM User,
                    $j:get_reservation_display_result  FROM TT_Teetimes_ILF

        DO      ADD $i PRECEDES $j;OD;


/* COORDINATE 6: Interaction between the User behaviors and TT/Teetimes ILF behaviors */
```

```
COORDINATE      $k:input_add_reservation_data          FROM User,
                $l:add_reservation_data                FROM TT_Teetimes_ILF

        DO ADD $k PRECEDES $l; OD;


/* COORDINATE 7: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE $m:input_change_reservation_data      FROM User,
                $n:change_reservation_data       FROM TT_Teetimes_ILF

        DO ADD $m PRECEDES $n; OD;


/* COORDINATE 8: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE      $o:input_delete_reservation_data       FROM User,
                $p:delete_reservation_data             FROM TT_Teetimes_ILF

        DO ADD $o PRECEDES $p; OD;

/* COORDINATE 9: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE      $q:inquire_on_maintain_golfcourses          FROM User,
                $r:get_maintain_golfcourses_result          FROM TT_GC_ILF

DO      ADD $q PRECEDES $r;OD;


/* COORDINATE 10: Interaction between the User behaviors and TT/Golfcourses ILF behaviors*/

COORDINATE      $s:input_add_maintain_golfcourses_data      FROM User,
                $t:add_maintain_golfcourses_data            FROM TT_GC_ILF

        DO ADD $s PRECEDES $t; OD;

/* COORDINATE 11: Interaction between the User behaviors and TT/Golfcourses ILF behaviors*/

COORDINATE      $u:input_change_maintain_golfcourses_data   FROM User,
                $v:change_maintain_golfcourses_data         FROM TT_GC_ILF

        DO ADD $u PRECEDES $v; OD;


/* COORDINATE 12: Interaction between the User behaviors and TT/Golfcourses ILF behaviors*/

COORDINATE      $w:input_delete_maintain_golfcourses_data       FROM User,
                $x:delete_maintain_golfcourses_data             FROM TT_GC_ILF

        DO ADD $w PRECEDES $x; OD;
```

```
/* COORDINATE 13: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE $y:inquire_on_scoreboard_display          FROM User,
           $z:get_scoreboard_display_result         FROM TT_Scoreboard_ILF

     DO    ADD $y PRECEDES $z; OD;


/* COORDINATE 14: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE  $aa:input_add_scoreboard_data         FROM User,
            $bb:add_scoreboard_data               FROM TT_Scoreboard_ILF

     DO ADD $aa PRECEDES $bb; OD;


/* COORDINATE 15: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE  $cc:input_change_scoreboard_data      FROM User,
            $dd:change_scoreboard_data            FROM TT_Scoreboard_ILF

     DO ADD $cc PRECEDES $dd; OD;

/* COORDINATE 16: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE  $ee:input_delete_scoreboard_data      FROM User,
            $ff:delete_scoreboard_data            FROM TT_Scoreboard_ILF

     DO ADD $ee PRECEDES $ff; OD;


/* COORDINATE 17: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE  $gg:inquire_on_shopping_display              FROM User,
                  $hh:get_shopping_display_result        FROM TT_Merchandise_EIF

     DO    ADD $gg PRECEDES $hh;OD;


/* COORDINATE 18: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE  $ii:inquire_on_product_display               FROM User,
```

```
                    $jj:get_product_display_result          FROM TT_Merchandise_EIF

        DO      ADD $ii PRECEDES $jj;OD;

/* COORDINATE 19: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE $kk:calculate_total_amount                       FROM User,
                $ll:get_calculated_total_amount             FROM TT_Merchandise_EIF

DO      ADD $kk PRECEDES $ll;OD;

/* COORDINATE 20: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE $mm:buy_product                                  FROM User,
        $nn:send_calculated_amount_to_purchasing            FROM TT_Merchandise_EIF
DO      ADD $mm PRECEDES $nn;OD;

/* SHARE All 1: Interaction between the IAA behaviors and the Golfcourse ILF behaviors */

TT, GC_ILF SHARE ALL writing;

/* SHARE All 2: Interaction between the IAA behaviors and the Teetimes ILF behaviors */

TT, Teetimes_ILF SHARE ALL writing;

/* SHARE All 3: Interaction between the IAA behaviors and the Scoreboard behaviors */

TT, Scoreboard_ILF SHARE ALL writing;

/* SHARE All 4: Interaction between the IAA behaviors and the Merchandise EIF behaviors */

TT, Merchandise_EIF SHARE ALL writing;
```

B. MP SCHEMA FOR COURSE OF ACTION 2

```
/*      Name: MP SCHEMA TeeTime_COA1_COA2 .
        Purpose: The It's Tee Time example for UFP estimate is derived from the It's Tee Time counting
        example, courtesy of Q/P Management Group. TeeTime source information is protected by
        copyright [56]. This example was refined and improvised by Monica Farah-Stapleton 06/20/16,
        and updated by Prof Mikhail Auguston, 06/22/16.
        Tool Used: MP Analyzed on Firebird
        Scope: 1                                                    */


SCHEMA TeeTime_COA1_COA2


/* ROOT User: Behaviors executed by the User of the It's Tee Time application */

ROOT User: (* ( (inquire_on_state_data
                            inquire_on_city_data
                            inquire_on_golfcourse_list
                            (* (inquire_on_golfcourse_detail | go_back )*)
                            inquire_on_reservation_display
                            (input_add_reservation_data |
 input_change_reservation_data |
 input_delete_reservation_data)
                                    inquire_on_maintain_golfcourses
                                    (input_add_maintain_golfcourses_data |
          input_change_maintain_golfcourses_data |
 input_delete_maintain_golfcourses_data) )
                           inquire_on_scoreboard_display
                            (input_add_scoreboard_data |
 input_change_scoreboard_data |
 input_delete_scoreboard_data)
                                    inquire_on_shopping_display
                                    (* (inquire_on_product_display
 calculate_total_amount
 buy_product )*)

                                                                    | exit)
                                    *);

/* ROOT TT_GC_ILF: The combined, relevant behaviors of the IAA and Golfcourses ILF */

ROOT TT_GC_ILF: (* (get_state_result
                                    get_city_result
                                    get_golfcourse_list_result
                                    get_golfcourse_detail_result
                                    get_maintain_golfcourses_result
                                    (*(add_maintain_golfcourses_data |
```

```
                change_maintain_golfcourses_data |
                delete_maintain_golfcourses_data)*) )


                        *);


/* ROOT TT_Teetimes_ILF: The combined, relevant behaviors of the IAA and Teetimes ILF */

ROOT TT_Teetimes_ILF: ( get_reservation_display_result
                                (*(add_reservation_data
                                        | change_reservation_data
                                                | delete_reservation_data)*)
                                );

/* ROOT TT_Scoreboard_ILF: The combined, relevant behaviors of the IAA and Scoreboard ILF */

ROOT TT_Scoreboard_ILF: ( get_scoreboard_display_result
                                        (*(add_scoreboard_data
                                                | change_scoreboard_data
                                                        | delete_scoreboard_data)*)
                                );

/* ROOT TT_Merchandise_EIF: The combined, relevant behaviors of the IAA and Merchandise EIF */

ROOT TT_Merchandise_EIF: ( get_shopping_display_result
                                        (*(get_product_display_result
                                        get_calculated_total_amount
                                        send_calculated_amount_to_purchasing)*)
                                );


/* ROOT TT: The relevant behaviors of the IAA */

ROOT TT: (* (writing | reading) *);


/* ROOT GC_ILF: The relevant behaviors of the Golfcourses ILF */

ROOT GC_ILF: (+writing +) (*sending*);


/* ROOT Teetimes_ILF: The relevant behaviors of the Teetimes ILF */

ROOT Teetimes_ILF: (+writing +) (*sending*);


/* ROOT Scoreboard_ILF: The relevant behaviors of the Teetimes ILF */

ROOT Scoreboard_ILF: (+writing +) (*sending*);
```

```
/* ROOT Merchandise_ILF: The relevant behaviors of the Merchandise EIF */

ROOT Merchandise_EIF: (+writing +) (*sending*);


/* COORDINATE 1: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE $a:inquire_on_state_data                    FROM User,
                   $b:get_state_result                 FROM TT_GC_ILF

DO      ADD $a PRECEDES $b;OD;


/* COORDINATE 2: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE $c:inquire_on_city_data                     FROM User,
           $d:get_city_result                          FROM TT_GC_ILF

DO      ADD $c PRECEDES $d;OD;

/* COORDINATE 3: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */


COORDINATE $e:inquire_on_golfcourse_list               FROM User,
           $f:get_golfcourse_list_result               FROM TT_GC_ILF

        DO      ADD $e PRECEDES $f;OD;

/* COORDINATE 4: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE      $g:inquire_on_golfcourse_detail        FROM User,
                $h:get_golfcourse_detail_result        FROM TT_GC_ILF

        DO      ADD $g PRECEDES $h;OD;


/* COORDINATE 5: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE      $i:inquire_on_reservation_display      FROM User,
                $j:get_reservation_display_result      FROM TT_Teetimes_ILF

        DO      ADD $i PRECEDES $j;OD;


/* COORDINATE 6: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE      $k:input_add_reservation_data          FROM User,
                $l:add_reservation_data                FROM TT_Teetimes_ILF
```

```
        DO ADD $k PRECEDES $l; OD;


/* COORDINATE 7: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE $m:input_change_reservation_data          FROM User,
           $n:change_reservation_data                FROM TT_Teetimes_ILF

        DO ADD $m PRECEDES $n; OD;


/* COORDINATE 8: Interaction between the User behaviors and TT/Teetimes ILF behaviors */

COORDINATE    $o:input_delete_reservation_data       FROM User,
              $p:delete_reservation_data             FROM TT_Teetimes_ILF

        DO ADD $o PRECEDES $p; OD;

/* COORDINATE 9: Interaction between the User behaviors and TT/Golfcourses ILF behaviors */

COORDINATE    $q:inquire_on_maintain_golfcourses     FROM User,
              $r:get_maintain_golfcourses_result     FROM TT_GC_ILF

DO      ADD $q PRECEDES $r;OD;


/* COORDINATE 10: Interaction between the User behaviors and TT/Golfcourses ILF behaviors*/

COORDINATE    $s:input_add_maintain_golfcourses_data     FROM User,
              $t:add_maintain_golfcourses_data           FROM TT_GC_ILF

        DO ADD $s PRECEDES $t; OD;

/* COORDINATE 11: Interaction between the User behaviors and TT/Golfcourses ILF behaviors*/

COORDINATE    $u:input_change_maintain_golfcourses_data  FROM User,
              $v:change_maintain_golfcourses_data        FROM TT_GC_ILF

        DO ADD $u PRECEDES $v; OD;


/* COORDINATE 12: Interaction between the User behaviors and TT/Golfcourses ILF behaviors*/

COORDINATE    $w:input_delete_maintain_golfcourses_data  FROM User,
              $x:delete_maintain_golfcourses_data        FROM TT_GC_ILF

        DO ADD $w PRECEDES $x; OD;
```

```
/* COORDINATE 13: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE $y:inquire_on_scoreboard_display                FROM User,
                $z:get_scoreboard_display_result           FROM TT_Scoreboard_ILF

        DO      ADD $y PRECEDES $z; OD;

/* COORDINATE 14: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE      $aa:input_add_scoreboard_data              FROM User,
                $bb:add_scoreboard_data                    FROM TT_Scoreboard_ILF

        DO ADD $aa PRECEDES $bb; OD;

/* COORDINATE 15: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE      $cc:input_change_scoreboard_data           FROM User,
                $dd:change_scoreboard_data                 FROM TT_Scoreboard_ILF

        DO ADD $cc PRECEDES $dd; OD;

/* COORDINATE 16: Interaction between the User behaviors and TT/Scoreboard ILF behaviors */

COORDINATE      $ee:input_delete_scoreboard_data           FROM User,
                $ff:delete_scoreboard_data                 FROM TT_Scoreboard_ILF

        DO ADD $ee PRECEDES $ff; OD;

/* COORDINATE 17: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE      $gg:inquire_on_shopping_display            FROM User,
                        $hh:get_shopping_display_result    FROM TT_Merchandise_EIF

        DO      ADD $gg PRECEDES $hh;OD;

/* COORDINATE 18: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE      $ii:inquire_on_product_display             FROM User,
                        $jj:get_product_display_result     FROM TT_Merchandise_EIF

        DO      ADD $ii PRECEDES $jj;OD;
```

```
/* COORDINATE 19: Interaction between the User behaviors and TT/Merchandise ILF behaviors */

COORDINATE $kk:calculate_total_amount                    FROM User,
           $ll:get_calculated_total_amount               FROM TT_Merchandise_EIF

DO      ADD $kk PRECEDES $ll;OD;


/* COORDINATE 20: Interaction between the User behaviors and TT/Merchandise ILF behaviors */


COORDINATE $mm:buy_product                               FROM User,
        $nn:send_calculated_amount_to_purchasing         FROM TT_Merchandise_EIF
DO      ADD $mm PRECEDES $nn;OD;


/* SHARE All 1: Interaction between the IAA behaviors and the Golfcourse ILF behaviors */

TT, GC_ILF SHARE ALL writing;


/* SHARE All 2: Interaction between the IAA behaviors and the Teetimes ILF behaviors */

TT, Teetimes_ILF SHARE ALL writing;


/* SHARE All 3: Interaction between the IAA behaviors and the Scoreboard behaviors */

TT, Scoreboard_ILF SHARE ALL writing;


/* SHARE All 4: Interaction between the IAA behaviors and the Merchandise EIF behaviors */

TT, Merchandise_EIF SHARE ALL writing;
```

C. MP SCHEMA FOR COURSE OF ACTION 3

The complete MP schema for COA 3 is included below for ease of inspection, to extract the data function types and transactional function types.

In order to run the model on Firebird, each MP model was split into two separate models, one that executed the data function types, and the other that executed the transactional function types. Breaking the model up did not affect the UFP count, but did allow the execution of the model in order to obtain event traces, to inform test case estimates.

```
/*      Name: MP SCHEMA COA 3 Nested COORDINATEs and SHARE ALL.
        Purpose: The It's Tee Time example for UFP estimate is derived from the It's Tee Time counting
        example, courtesy of Q/P Management Group. TeeTime source information is protected by
        copyright [56]. This example was refined and improvised by Monica Farah-Stapleton 06/20/16,
        and updated by Prof Mikhail Auguston, 06/22/16.
        Tool Used: MP Analyzed on Firebird
        Scope: 1                                                    */


SCHEMA TeeTime_ Nested_COORDINATEs_SHARE ALL

/* ROOT User: Behaviors executed by the User of the It's Tee Time application */

 ROOT User: (* ( (inquire_on_state_data
                                inquire_on_city_data
                                inquire_on_golfcourse_list
                                (* (inquire_on_golfcourse_detail | go_back )*)
                                inquire_on_reservation_display
                                (input_add_reservation_data |
 input_change_reservation_data |
 input_delete_reservation_data)
                                        inquire_on_maintain_golfcourses
                                        (input_add_maintain_golfcourses_data |
 input_change_maintain_golfcourses_data |
 input_delete_maintain_golfcourses_data) )
                               inquire_on_scoreboard_display
                                (input_add_scoreboard_data |
 input_change_scoreboard_data |
 input_delete_scoreboard_data)
                                        inquire_on_shopping_display
                                        (* (inquire_on_product_display
 calculate_total_amount
 buy_product )*)
                                                                                | exit)
```

```
                *);

        inquire_on_state_data: click_state_arrow_dropdown receive_state_list_display;
        inquire_on_city_data: view_state_data_entered click_on_city_arrow_dropdown
        receive_city_list_display;

inquire_on_golfcourse_list: view_state_data_entered view_city_data_entered
        click_list_display_button view_golfcourse_name_displayed;

inquire_on_golfcourse_detail: click_icon_from_golfcourse_list request_id
        request_name    request_address request_city    request_state    request_zip
        request_phone   request_description     request_slope    request_fees
        request_requirements;

inquire_on_reservation_display:    carryover_id              carryover_coursename
        click_on_date_dropdown click_display    request_time    request_no_of_players
        request_no_of_holes    request_name request_cc_type    request_cc_no
        request_phone_no;

input_add_reservation_data:     input_id        input_coursename        input_date
        input_time
        input_no_players input_no_holes  input_name     input_cc_type    input_cc_no
        input_phone_no click_add_button receive_error_confirmation_message;


input_change_reservation_data: input_change_id    input_change_coursename
        input_change_date       input_change_time input_change_no_players
        input_change_no_holes
        input_change_name       input_change_cc_type    input_change_cc_no
        input_change_phone_no click_change_button       receive_error_confirmation_message;


input_delete_reservation_data: input_delete_id     input_delete_coursename
        input_delete_date       input_delete_time click_delete_button
        receive_error_confirmation_message;

inquire_on_maintain_golfcourses: enter_coursename       click_display_button     request_id
        request_address request_city request_state      request_zip     request_phone
        request_description     request_slope    request_fees    request_requirements
        receive_error_confirmation_message;

input_add_maintain_golfcourses_data: input_add_coursename       input_add_address
        input_add_city
        input_add_state  input_add_zip    input_add_phone       input_add_description
        input_add_slope  input_add_fees input_add_requirements    click_add_button receive_id
        receive_error_confirmation_message;

input_change_maintain_golfcourses_data: input_change_coursename input_change_address
        input_change_city       input_change_state      input_change_zip
        input_change_phone      input_change_description input_change_slope
```

```
        input_change_fees       input_change_requirements       click_change_button
        receive_id      receive_error_confirmation_message;

input_delete_maintain_golfcourses_data: input_delete_id click_delete_button
        receive_error_confirmation_message;

inquire_on_scoreboard_display: click_scoreboard_icon      request_name    request_course
        request_date    request_slope    request_score;

input_add_scoreboard_data: input_add_name      input_add_course      input_add_date
        input_add_slope input_add_score click_add_button
        receive_error_confirmation_message;

input_change_scoreboard_data: input_change_name      input_change_course
        input_change_date       input_change_slope      input_change_score
        click_change_button     receive_error_confirmation_message;

input_delete_scoreboard_data: highlight_name click_delete_button
        receive_error_confirmation_message;

inquire_on_shopping_display: click_teetime_shopping_icon   request_product  request_unit_price;

inquire_on_product_display: click_view_icon request_image receive_error_confirmation_message;

calculate_total_amount: enter_quantity calculate_price_action calculate_price
        calculate_quantity      calculate_total_for_row         calculate_total_bill
        receive_error_confirmation_message;

buy_product: click_buy_button    receive_product  receive_price    receive_quantity
        receive_row_total       receive_bill_total receive_cc_type  receive_cc_number
        receive_expiration_date  receive_mailing_name    receive_address         receive_city
        receive_state receive_zip  receive_error_confirmation_message;



/* ROOT TT_GC_ILF: The combined, relevant behaviors of the IAA and Golfcourses ILF */

ROOT TT_GC_ILF: (* (get_state_result
                                get_city_result
                                get_golfcourse_list_result
                                get_golfcourse_detail_result
                                get_maintain_golfcourses_result
                                (*(add_maintain_golfcourses_data |
                change_maintain_golfcourses_data |
                delete_maintain_golfcourses_data)*) )


                        *);

get_state_result: receive_state_arrow_prompt send_state_list_display;
```

```
get_city_result: send_state_data_entered receive_city_arrow_prompt
        send_city_list_display;

get_golfcourse_list_result: send_state_data_entered send_city_data_entered
        receive_list_display_button_prompt send_golfcourse_name_displayed;

get_golfcourse_detail_result:    get_golfcourse_detail_results    send_id
        send_name    send_address    send_city    send_state    send_zip
        send_phone    send_description    send_slope    send_fees
        send_requirements;

get_maintain_golfcourses_result: view_coursename receive_display_button_prompt    send_id
        send_address send_city send_state    send_zip    send_phone    send_description
        send_slope send_fees send_requirements    send_error_confirmation_message;

add_maintain_golfcourses_data: add_coursename    add_address    add_city
        add_state    add_zip    add_phone    add_description    add_slope
        add_fees add_requirements    receive_add_button_prompt    send_id
        send_error_confirmation_message;

change_maintain_golfcourses_data: change_coursename    change_address    change_city
        change_state    change_zip    change_phone    change_description    change_slope
        change_fees change_requirements receive_change_button_prompt    send_id
        send_error_confirmation_message;



delete_maintain_golfcourses_data: delete_id    receive_delete_button_prompt
        send_error_confirmation_message;




/* ROOT TT_Teetimes_ILF: The combined, relevant behaviors of the IAA and Teetimes ILF */

ROOT TT_Teetimes_ILF: ( get_reservation_display_result
                        (*(add_reservation_data
                                | change_reservation_data
                                        | delete_reservation_data)*)
                        );


get_reservation_display_result:    display_id    display_coursename    display_date
        send_display_results    send_time send_no_of_players    send_no_of_holes
        send_name    send_cc_type    send_cc_no    send_phone_no;

add_reservation_data: add_id    add_coursename add_date    add_time
        add_no_players  add_no_holes    add_name    add_cc_type    add_cc_no
```

```
        add_phone_no receive_add_button_response        send_error_confirmation_message;


change_reservation_data: change_id          change_coursename
        change_date      change_time        change_no_players        change_no_holes
        change_name      change_cc_type     change_cc_no
        change_phone_no receive_change_button_response
        send_error_confirmation_message;

delete_reservation_data: delete_id          delete_coursename
        delete_date      delete_time        receive_delete_button_response
        send_error_confirmation_message;



/* ROOT TT_Scoreboard_ILF: The combined, relevant behaviors of the IAA and Scoreboard ILF */

ROOT TT_Scoreboard_ILF: ( get_scoreboard_display_result
                                (*(add_scoreboard_data
                                        | change_scoreboard_data
                                                | delete_scoreboard_data)*)
                                );


get_scoreboard_display_result: receive_scoreboard_icon_prompt      send_name        send_course
        send_date        send_slope        send_score;

add_scoreboard_data: add_name  add_course       add_date add_slope add_score
        receive_add_button_response             send_error_confirmation_message;

change_scoreboard_data: change_name     change_course    change_date      change_slope
        change_score     receive_change_button_response send_error_confirmation_message;

delete_scoreboard_data: delete_name receive_delete_button_prompt
        send_error_confirmation_message;
/* ROOT TT_Merchandise_ILF: The combined, relevant behaviors of the IAA and Merchandise EIF */

ROOT TT_Merchandise_EIF: ( get_shopping_display_result
                                (*(get_product_display_result get_calculated_total_amount
                                send_calculated_amount_to_purchasing)*)
                                );

get_shopping_display: receive_teetime_shopping_icon_prompt        send_product
                        send_unit_price;

get_product_display: receive_view_icon_prompt     send_image
                send_error_confirmation_message;

get_calculated_total_amount:       receive_quantity receive_calculate_price_action_prompt
        send_price       send_quantity send_total_for_row  send_total_bill
        send_error_confirmation_message;
```

```
send_calculated_amount_to_purchasing: receive_buy_button_prompt          send_product
        send_price        send_quantity    send_row_total  send_bill_total          send_cc_type
        send_cc_number send_expiration_date      send_mailing_name              send_address
        send_city                 send_state                send_zip
        send_error_confirmation_message;



/* ROOT TT: The relevant behaviors of the IAA */
ROOT TT: (* (writing | reading) *);

/* ROOT GC_ILF: The relevant behaviors of the Golfcourses ILF */
ROOT GC_ILF: (+writing +) (*sending*);

/* ROOT Teetimes_ILF: The relevant behaviors of the Teetimes ILF */
ROOT Teetimes_ILF: (+writing +) (*sending*);

/* ROOT Scoreboard_ILF: The relevant behaviors of the Teetimes ILF */
ROOT Scoreboard_ILF: (+writing +) (*sending*);

/* ROOT Merchandise_EIF: The relevant behaviors of the Merchandise EIF */
ROOT Merchandise_EIF: (+writing +) (*sending*);


/* COORDINATE 1: Interaction between the User behaviors and TT/Golfcourses ILF behaviors , and nested
COORDINATE with 2 ADDs representing 2 DETs */

COORDINATE $a:inquire_on_state_data                    FROM User,
                $b:get_state_result                    FROM TT_GC_ILF

DO

                COORDINATE

                $ax: click_state_arrow_dropdown        FROM $a,
                $bx: receive_state_arrow_prompt        FROM $b,
                $axx: receive_state_list_display       FROM $a,
                $bxx: send_state_list_display          FROM $b
        DO


                ADD $ax PRECEDES $bx;
                ADD $bxx PRECEDES $axx;
        OD;
OD;


/* COORDINATE 2: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 3 ADDs representing 3 DETs*/
```

```
COORDINATE $c:inquire_on_city_data              FROM User,
           $d:get_city_result                   FROM TT_GC_ILF

DO

        COORDINATE

                $cx1: view_state_data_entered                   FROM $c,
                $dx1: send_state_data_entered                   FROM $d,
                $cx2: click_on_city_arrow_dropdown              FROM $c,
                $dx2: receive_city_arrow_prompt                 FROM $d,
                $cx3: receive_city_list_display                 FROM $c,
                $dx3: send_city_list_display                    FROM $d

    DO
        ADD $cx1 PRECEDES $dx1;
        ADD $cx2 PRECEDES $dx2;
        ADD $dx3 PRECEDES $cx3;

    OD;
OD;


/* COORDINATE 3: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 4 ADDs representing 4 DETs */

COORDINATE $e:inquire_on_golfcourse_list                FROM User,
           $f:get_golfcourse_list_result                FROM TT_GC_ILF

DO

COORDINATE
                $ex1: view_state_data_entered                   FROM $e,
                $fx1: send_state_data_entered                   FROM $f,
                $ex2: view_city_data_entered                    FROM $e,
                $fx2: send_city_data_entered                    FROM $f,
                $ex3: click_list_display_button                 FROM $e,
                $fx3: receive_list_display_button_prompt        FROM $f,
                $ex4: view_golfcourse_name_displayed            FROM $e,
                $fx4: send_golfcourse_name_displayed            FROM $f

    DO
        ADD $ex1 PRECEDES $fx1;
        ADD $ex2 PRECEDES $fx2;
        ADD $ex3 PRECEDES $fx3;
        ADD $fx4 PRECEDES $ex4;

    OD;
OD;
```

```
/* COORDINATE 4: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 12 ADDs representing 12 DETs */

COORDINATE $g: inquire_on_golfcourse_detail        FROM User,
               $h: get_golfcourse_detail_result    FROM TT_GC_ILF

DO

COORDINATE


                    $gx1: click_icon_from_golfcourse_list          FROM $g,
                    $hx1: get_golfcourse_detail_results            FROM $h,
                    $gx2: request_id                               FROM $g,
                    $hx2: send_id                                  FROM $h,
                    $gx3: request_name                             FROM $g,
                    $hx3: send_name                                FROM $h,
                    $gx4: request_address                          FROM $g,
                    $hx4: send_address                             FROM $h,
                    $gx5: request_city                             FROM $g,
                    $hx5: send_city                                FROM $h,
                    $gx6: request_state                            FROM $g,
                    $hx6: send_state                               FROM $h,
                    $gx7: request_zip                              FROM $g,
                    $hx7: send_zip                                 FROM $h,
                    $gx8: request_phone                            FROM $g,
                    $hx8: send_phone                               FROM $h,
                    $gx9: request_description                      FROM $g,
                    $hx9: send_description                         FROM $h,
                    $gx10: request_slope                           FROM $g,
                    $hx10: send_slope                              FROM $h,
                    $gx11: request_fees                            FROM $g,
                    $hx11: send_fees                               FROM $h,
                    $gx12: request_requirements                    FROM $g,
                    $hx12: send_requirements                       FROM $h

          DO
                    ADD $gx1 PRECEDES $hx1;
                    ADD $gx2 PRECEDES $hx2;
                    ADD $gx3 PRECEDES $hx3;
                    ADD $gx4 PRECEDES $hx4;
                    ADD $gx5 PRECEDES $hx5;
                    ADD $gx6 PRECEDES $hx6;
                    ADD $gx7 PRECEDES $hx7;
                    ADD $gx8 PRECEDES $hx8;
                    ADD $gx9 PRECEDES $hx9;
                    ADD $gx10 PRECEDES $hx10;
                    ADD $gx11 PRECEDES $hx11;
```

```
                ADD $hx12 PRECEDES $gx12;


        OD;
OD;


/* COORDINATE 5: Interaction between the User behaviors and TT/Teetimes ILF behaviors, and nested
COORDINATE with 11 ADDs representing 11 DETs */

COORDINATE $i:inquire_on_reservation_display        FROM User,
                $j:get_reservation_display_result   FROM TT_Teetimes_ILF

        DO

        COORDINATE


                $ix1: carryover_id                  FROM $i,
                $jx1: display_id                    FROM $j,
                $ix2: carryover_coursename          FROM $i,
                $jx2: display_coursename            FROM $j,
                $ix3: click_on_date_dropdown        FROM $i,
                $jx3: display_date                  FROM $j,
                $ix4: click_display                 FROM $i,
                $jx4: send_display_results          FROM $j,
                $ix5: request_time                  FROM $i,
                $jx5: send_time                     FROM $j,
                $ix6: request_no_of_players         FROM $i,
                $jx6: send_no_of_players            FROM $j,
                $ix7: request_no_of_holes           FROM $i,
                $jx7: send_no_of_holes              FROM $j,
                $ix8: request_name                  FROM $i,
                $jx8: send_name                     FROM $j,
                $ix9: request_cc_type               FROM $i,
                $jx9: send_cc_type                  FROM $j,
                $ix10: request_cc_no                FROM $i,
                $jx10: send_cc_no                   FROM $j,
                $ix11: request_phone_no             FROM $i,
                $jx11: send_phone_no                FROM $j

        DO
                ADD $ix1 PRECEDES $jx1;
                ADD $ix2 PRECEDES $jx2;
                ADD $ix3 PRECEDES $jx3;
                ADD $ix4 PRECEDES $jx4;
                ADD $ix5 PRECEDES $jx5;
                ADD $ix6 PRECEDES $jx6;
                ADD $ix7 PRECEDES $jx7;
                ADD $ix8 PRECEDES $jx8;
                ADD $ix9 PRECEDES $jx9;
```

```
                ADD $ix10 PRECEDES $jx10;
                ADD $jx11 PRECEDES $ix11;


        OD;
OD;


/* COORDINATE 6: Interaction between the User behaviors and TT/Teetimes ILF behaviors and nested
COORDINATE with 12 ADDs representing 12 DETs */

COORDINATE $k: input_add_reservation_data                FROM User,
                $l:add_reservation_data                  FROM TT_Teetimes_ILF
DO

        COORDINATE

                        $kx1: input_id                                  FROM $k,
                        $lx1: add_id                                    FROM $l,
                        $kx2: input_coursename                          FROM $k,
                        $lx2: add_coursename                            FROM $l,
                        $kx3: input_date                                FROM $k,
                        $lx3: add_date                                  FROM $l,
                        $kx4: input_time                                FROM $k,
                        $lx4: add_time                                  FROM $l,
                        $kx5: input_no_players                          FROM $k,
                        $lx5: add_no_players                            FROM $l,
                        $kx6: input_no_holes                            FROM $k,
                        $lx6: add_no_holes                              FROM $l,
                        $kx7: input_name                                FROM $k,
                        $lx7: add_name                                  FROM $l,
                        $kx8: input_cc_type                             FROM $k,
                        $lx8: add_cc_type                               FROM $l,
                        $kx9: input_cc_no                               FROM $k,
                        $lx9: add_cc_no                                 FROM $l,
                        $kx10: input_phone_no                           FROM $k,
                        $lx10: add_phone_no                             FROM $l,
                        $kx11: click_add_button                         FROM $k,
                        $lx11: receive_add_button_response              FROM $l,
                        $kx12: receive_error_confirmation_message       FROM $k,
                        $lx12: send_error_confirmation_message          FROM $l

        DO


                ADD $kx1 PRECEDES $lx1;
                ADD $kx2 PRECEDES $lx2;
                ADD $kx3 PRECEDES $lx3;
                ADD $kx4 PRECEDES $lx4;
                ADD $kx5 PRECEDES $lx5;
                ADD $kx6 PRECEDES $lx6;
```

```
                ADD $kx7 PRECEDES $lx7;
                ADD $kx8 PRECEDES $lx8;
                ADD $kx9 PRECEDES $lx9;
                ADD $kx10 PRECEDES $lx10;
                ADD $kx11 PRECEDES $lx11;
                ADD $lx12 PRECEDES $kx12;


        OD;
OD;


/* COORDINATE 7: Interaction between the User behaviors and TT/Teetimes ILF behaviors, and nested
COORDINATE with 12 ADDs representing 12 DETs */

COORDINATE $m: input_change_reservation_data    FROM User,
                $n:change_reservation_data              FROM TT_Teetimes_ILF

DO

        COORDINATE

                        $mx1: input_change_id                           FROM $m,
                        $nx1: change_id                                 FROM $n,
                        $mx2: input_change_coursename                   FROM $m,
                        $nx2: change_coursename                         FROM $n,
                        $mx3: input_change_date                         FROM $m,
                        $nx3: change_date                               FROM $n,
                        $mx4: input_change_time                         FROM $m,
                        $nx4: change_time                               FROM $n,
                        $mx5: input_change_no_players                   FROM $m,
                        $nx5: change_no_players                         FROM $n,
                        $mx6: input_change_no_holes                     FROM $m,
                        $nx6: change_no_holes                           FROM $n,
                        $mx7: input_change_name                         FROM $m,
                        $nx7: change_name                               FROM $n,
                        $mx8: input_change_cc_type                      FROM $m,
                        $nx8: change_cc_type                            FROM $n,
                        $mx9: input_change_cc_no                        FROM $m,
                        $nx9: change_cc_no                              FROM $n,
                        $mx10: input_change_phone_no                    FROM $m,
                        $nx10: change_phone_no                          FROM $n,
                        $mx11: click_change_button                      FROM $m,
                        $nx11: receive_change_button_response           FROM $n,
                        $mx12: receive_error_confirmation_message       FROM $m,
                        $nx12: send_error_confirmation_message          FROM $n

        DO


                ADD $mx1 PRECEDES $nx1;
```

```
                ADD $mx2 PRECEDES $nx2;
                ADD $mx3 PRECEDES $nx3;
                ADD $mx4 PRECEDES $nx4;
                ADD $mx5 PRECEDES $nx5;
                ADD $mx6 PRECEDES $nx6;
                ADD $mx7 PRECEDES $nx7;
                ADD $mx8 PRECEDES $nx8;
                ADD $mx9 PRECEDES $nx9;
                ADD $mx10 PRECEDES $nx10;
                ADD $mx11 PRECEDES $nx11;
                ADD $nx12 PRECEDES $mx12;
        OD;
OD;



/* COORDINATE 8: Interaction between the User behaviors and TT/Teetimes ILF behaviors, and nested
COORDINATE with 6 ADDs representing 6 DETs */

COORDINATE $o:input_delete_reservation_data FROM User,
                $p:delete_reservation_data              FROM TT_Teetimes_ILF
DO

        COORDINATE

                        $ox1: input_delete_id                           FROM $o,
                        $px1: delete_id                                 FROM $p,
                        $ox2: input_delete_coursename                   FROM $o,
                        $px2: delete_coursename                         FROM $p,
                        $ox3: input_delete_date                         FROM $o,
                        $px3: delete_date                               FROM $p,
                        $ox4: input_delete_time                         FROM $o,
                        $px4: delete_time                               FROM $p,
                        $ox5: click_delete_button                       FROM $o,
                        $px5: receive_delete_button_response            FROM $p,
                        $ox6: receive_error_confirmation_message        FROM $o,
                        $px6: send_error_confirmation_message           FROM $p

        DO
                ADD $ox1 PRECEDES $px1;
                ADD $ox2 PRECEDES $px2;
                ADD $ox3 PRECEDES $px3;
                ADD $ox4 PRECEDES $px4;
                ADD $ox5 PRECEDES $px5;
                ADD $px6 PRECEDES $ox6;
        OD;
OD;
```

```
/* COORDINATE 9: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 13 ADDs representing 13 DETs */

COORDINATE $q:inquire_on_maintain_golfcourses                FROM User,
           $r:get_maintain_golfcourses_result                FROM TT_GC_ILF

     DO

     COORDINATE

          $qx1: enter_coursename                             FROM $q,
          $rx1: view_coursename                              FROM $r,
          $qx2: click_display_button                         FROM $q,
          $rx2: receive_display_button_prompt                FROM $r,
          $qx3: request_id                                   FROM $q,
          $rx3: send_id                                      FROM $r,
          $qx4: request_address                              FROM $q,
          $rx4: send_address                                 FROM $r,
          $qx5: request_city                                 FROM $q,
          $rx5: send_city                                    FROM $r,
          $qx6: request_state                                FROM $q,
          $rx6: send_state                                   FROM $r,
          $qx7: request_zip                                  FROM $q,
          $rx7: send_zip                                     FROM $r,
          $qx8: request_phone                                FROM $q,
          $rx8: send_phone                                   FROM $r,
          $qx9: request_description                          FROM $q,
          $rx9: send_description                             FROM $r,
          $qx10: request_slope                               FROM $q,
          $rx10: send_slope                                  FROM $r,
          $qx11: request_fees                                FROM $q,
          $rx11: send_fees                                   FROM $r,
          $qx12: request_requirements                        FROM $q,
          $rx12: send_requirements                           FROM $r,
          $qx13: receive_error_confirmation_message          FROM $q,
          $rx13: send_error_confirmation_message             FROM $r


     DO
          ADD $qx1 PRECEDES $rx1;
          ADD $qx2 PRECEDES $rx2;
          ADD $qx3 PRECEDES $rx3;
          ADD $qx4 PRECEDES $rx4;
          ADD $qx5 PRECEDES $rx5;
          ADD $qx6 PRECEDES $rx6;
          ADD $qx7 PRECEDES $rx7;
          ADD $qx8 PRECEDES $rx8;
          ADD $qx9 PRECEDES $rx9;
          ADD $qx10 PRECEDES $rx10;
          ADD $qx11 PRECEDES $rx11;
```

```
                ADD $qx12 PRECEDES $rx12;
                ADD $rx13 PRECEDES $qx13;


        OD;
OD;


/* COORDINATE 10: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and
nested COORDINATE with 13 ADDs representing 13 DETs */

COORDINATE $s:input_add_maintain_golfcourses_data        FROM User,
                $t:add_maintain_golfcourses_data         FROM TT_GC_ILF
        DO

        COORDINATE

                $sx1: input_add_coursename               FROM $s,
                $tx1: add_coursename                     FROM $t,
                $sx2: input_add_address                  FROM $s,
                $tx2: add_address                        FROM $t,
                $sx3: input_add_city                     FROM $s,
                $tx3: add_city                           FROM $t,
                $sx4: input_add_state                    FROM $s,
                $tx4: add_state                          FROM $t,
                $sx5: input_add_zip                      FROM $s,
                $tx5: add_zip                            FROM $t,
                $sx6: input_add_phone                    FROM $s,
                $tx6: add_phone                          FROM $t,
                $sx7: input_add_description              FROM $s,
                $tx7: add_description                    FROM $t,
                $sx8: input_add_slope                    FROM $s,
                $tx8: add_slope                          FROM $t,
                $sx9: input_add_fees                     FROM $s,
                $tx9: add_fees                           FROM $t,
                $sx10: input_add_requirements            FROM $s,
                $tx10: add_requirements                  FROM $t,
                $sx11: click_add_button                  FROM $s,
                $tx11: receive_add_button_prompt         FROM $t,
                $sx12: receive_id                        FROM $s,
                $tx12: send_id                           FROM $t,
                $sx13: receive_error_confirmation_message FROM $s,
                $tx13: send_error_confirmation_message   FROM $t

        DO
                ADD $sx1 PRECEDES $tx1;
                ADD $sx2 PRECEDES $tx2;
                ADD $sx3 PRECEDES $tx3;
                ADD $sx4 PRECEDES $tx4;
                ADD $sx5 PRECEDES $tx5;
```

```
                ADD $sx6 PRECEDES $tx6;
                ADD $sx7 PRECEDES $tx7;
                ADD $sx8 PRECEDES $tx8;
                ADD $sx9 PRECEDES $tx9;
                ADD $sx10 PRECEDES $tx10;
                ADD $sx11 PRECEDES $tx11;
                ADD $tx12 PRECEDES $sx12;
                ADD $tx13 PRECEDES $sx13;

        OD;
OD;


/* COORDINATE 11: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and
nested COORDINATE with 13 ADDs representing 13 DETs */

COORDINATE $u:input_change_maintain_golfcourses_data    FROM User,
                $v:change_maintain_golfcourses_data     FROM TT_GC_ILF

        DO

        COORDINATE

                $ux1: input_change_coursename                   FROM $u,
                $vx1: change_coursename                         FROM $v,
                $ux2: input_change_address                      FROM $u,
                $vx2: change_address                            FROM $v,
                $ux3: input_change_city                         FROM $u,
                $vx3: change_city                               FROM $v,
                $ux4: input_change_state                        FROM $u,
                $vx4: change_state                              FROM $v,
                $ux5: input_change_zip                          FROM $u,
                $vx5: change_zip                                FROM $v,
                $ux6: input_change_phone                        FROM $u,
                $vx6: change_phone                              FROM $v,
                $ux7: input_change_description                  FROM $u,
                $vx7: change_description                        FROM $v,
                $ux8: input_change_slope                        FROM $u,
                $vx8: change_slope                              FROM $v,
                $ux9: input_change_fees                         FROM $u,
                $vx9: change_fees                               FROM $v,
                $ux10: input_change_requirements                FROM $u,
                $vx10: change_requirements                      FROM $v,
                $ux11: click_change_button                      FROM $u,
                $vx11: receive_change_button_prompt             FROM $v,
                $ux12: receive_id                               FROM $u,
                $vx12: send_id                                  FROM $v,
                $ux13: receive_error_confirmation_message       FROM $u,
                $vx13: send_error_confirmation_message          FROM $v
```

```
        DO
                ADD $ux1 PRECEDES $vx1;
                ADD $ux2 PRECEDES $vx2;
                ADD $ux3 PRECEDES $vx3;
                ADD $ux4 PRECEDES $vx4;
                ADD $ux5 PRECEDES $vx5;
                ADD $ux6 PRECEDES $vx6;
                ADD $ux7 PRECEDES $vx7;
                ADD $ux8 PRECEDES $vx8;
                ADD $ux9 PRECEDES $vx9;
                ADD $ux10 PRECEDES $vx10;
                ADD $ux11 PRECEDES $vx11;
                ADD $vx12 PRECEDES $ux12;
                ADD $vx13 PRECEDES $ux13;


        OD;
OD;


/* COORDINATE 12: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and
nested COORDINATE with 3 ADDs representing 3 DETs */
COORDINATE $w:input_delete_maintain_golfcourses_data        FROM User,
                $x:delete_maintain_golfcourses_data         FROM TT_GC_ILF

DO

        COORDINATE

                $wx1: input_delete_id                       FROM $w,
                $xx1: delete_id                             FROM $x,
                $wx2: click_delete_button                   FROM $w,
                $xx2: receive_delete_button_prompt          FROM $x,
                $wx3: input_change_city                     FROM $w,
                $xx3: change_city                           FROM $x



        DO
                ADD $wx1 PRECEDES $xx1;
                ADD $xx2 PRECEDES $wx2;
                ADD $xx3 PRECEDES $wx3;


        OD;
OD;
```

```
/* COORDINATE 13: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 6 ADDs representing 6 DETs */

COORDINATE $y: inquire_on_scoreboard_display        FROM User,
               $z: get_scoreboard_display_result    FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $yx1: click_scoreboard_icon                     FROM $y,
                $zx1: receive_scoreboard_icon_prompt            FROM $z,
                $yx2: request_name                              FROM $y,
                $zx2: send_name                                 FROM $z,
                $yx3: request_course                            FROM $y,
                $zx3: send_course                               FROM $z,
                $yx4: request_date                              FROM $y,
                $zx4: send_date                                 FROM $z,
                $yx5: request_slope                             FROM $y,
                $zx5: send_slope                                FROM $z,
                $yx6: request_score                             FROM $y,
                $zx6: send_score                                FROM $z

        DO
                ADD $yx1 PRECEDES $zx1;
                ADD $yx2 PRECEDES $zx2;
                ADD $yx3 PRECEDES $zx3;
                ADD $yx4 PRECEDES $zx4;
                ADD $yx5 PRECEDES $zx5;
                ADD $yx6 PRECEDES $zx6;

        OD;
OD;


/* COORDINATE 14: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 7 ADDs representing 7 DETs */


COORDINATE $aa: input_add_scoreboard_data        FROM User,
                $bb: add_scoreboard_data         FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $aax1: input_add_name                   FROM $aa,
                $bbx1: add_name                         FROM $bb,
                $aax2: input_add_course                 FROM $aa,
                $bbx2: add_course                       FROM $bb,
                $aax3: input_add_date                   FROM $aa,
```

```
                $bbx3: add_date                                 FROM $bb,
                $aax4: input_add_slope                          FROM $aa,
                $bbx4: add_slope                                FROM $bb,
                $aax5: input_add_score                          FROM $aa,
                $bbx5: add_score                                FROM $bb,
                $aax6: click_add_button                         FROM $aa,
                $bbx6: receive_add_button_response              FROM $bb,
                $aax7: receive_error_confirmation_message       FROM $aa,
                $bbx7: send_error_confirmation_message          FROM $bb


        DO
                ADD $aax1 PRECEDES $bbx1;
                ADD $aax2 PRECEDES $bbx2;
                ADD $aax3 PRECEDES $bbx3;
                ADD $aax4 PRECEDES $bbx4;
                ADD $aax5 PRECEDES $bbx5;
                ADD $aax6 PRECEDES $bbx6;
                ADD $aax7 PRECEDES $bbx7;

        OD;
OD;


/* COORDINATE 15: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 7 ADDs representing 7 DETs */


COORDINATE $cc: input_change_scoreboard_data            FROM User,
                $dd: change_scoreboard_data             FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $ccx1: input_change_name                FROM $cc,
                $ddx1: change_name                      FROM $dd,
                $ccx2: input_change_course              FROM $cc,
                $ddx2: change_course                    FROM $dd,
                $ccx3: input_change_date                FROM $cc,
                $ddx3: change_date                      FROM $dd,
                $ccx4: input_change_slope               FROM $cc,
                $ddx4: change_slope                     FROM $dd,
                $ccx5: input_change_score               FROM $cc,
                $ddx5: change_score                     FROM $dd,
                $ccx6: click_change_button              FROM $cc,
                $ddx6: receive_change_button_response   FROM $dd,
                $ccx7: receive_error_confirmation_message FROM $cc,
                $ddx7: send_error_confirmation_message  FROM $dd
```

```
        DO
                ADD $ccx1 PRECEDES $ddx1;
                ADD $ccx2 PRECEDES $ddx2;
                ADD $ccx3 PRECEDES $ddx3;
                ADD $ccx4 PRECEDES $ddx4;
                ADD $ccx5 PRECEDES $ddx5;
                ADD $ccx6 PRECEDES $ddx6;
                ADD $ccx7 PRECEDES $ddx7;

        OD;
OD;
```

/* COORDINATE 16: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested COORDINATE with 3 ADDs representing 3 DETs */

```
COORDINATE $ee: input_delete_scoreboard_data        FROM User,
                $ff: delete_scoreboard_data         FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $eex1: highlight_name                                   FROM $ee,
                $ffx1: delete_name                                      FROM $ff,
                $eex2: click_delete_button                              FROM $ee,
                $ffx2: receive_delete_button_prompt                     FROM $ff,
                $eex3: receive_error_confirmation_message               FROM $ee,
                $ffx3: send_error_confirmation_message                  FROM $ff


        DO
                ADD $eex1 PRECEDES $ffx1;
                ADD $eex2 PRECEDES $ffx2;
                ADD $ffx3 PRECEDES $eex3;

        OD;
OD;
```

/* COORDINATE 17: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and nested COORDINATE with 3 ADDs representing 3 DETs */

```
COORDINATE $gg: inquire_on_shopping_display         FROM User,
                $hh: get_shopping_display_result    FROM TT_Merchandise_EIF
```

```
DO
        COORDINATE
                $ggx1: click_teetime_shopping_icon                  FROM $gg,
                $hhx1: receive_teetime_shopping_icon_prompt         FROM $hh,
                $ggx2: request_product                              FROM $gg,
                $hhx2: send_product                                 FROM $hh,
                $ggx3: request_unit_price                           FROM $gg,
                $hhx3: send_unit_price                              FROM $hh


        DO
                ADD $ggx1 PRECEDES $hhx1;
                ADD $ggx2 PRECEDES $hhx2;
                ADD $hhx3 PRECEDES $ggx3;

        OD;
OD;

/* COORDINATE 18: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and
nested COORDINATE with 3 ADDs representing 3 DETs */


COORDINATE $ii:inquire_on_product_display            FROM User,
                $jj:get_product_display_result       FROM TT_Merchandise_EIF


DO
        COORDINATE
                $iix1: click_view_icon                          FROM $ii,
                $jjx1: receive_view_icon_prompt                 FROM $jj,
                $iix2: request_image                            FROM $ii,
                $jjx2: send_image                               FROM $jj,
                $iix3: receive_error_confirmation_message       FROM $ii,
                $jjx3: send_error_confirmation_message          FROM $jj


        DO
                ADD $iix1 PRECEDES $jjx1;
                ADD $iix2 PRECEDES $jjx2;
                ADD $jjx3 PRECEDES $iix3;

        OD;
OD;
```

```
/* COORDINATE 19: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and
nested COORDINATE with 7 ADDs representing 7 DETs */

COORDINATE $kk: calculate_total_amount                    FROM User,
        $ll:get_calculated_total_amount                   FROM TT_Merchandise_EIF

DO

        COORDINATE

                $kkx1: enter_quantity                     FROM $kk,
                $llx1: receive_quantity                   FROM $ll,
                $kkx2: calculate_price_action             FROM $kk,
                $llx2: receive_calculate_price_action_prompt FROM $ll,
                $kkx3: calculate_price                    FROM $kk,
                $llx3: send_price                         FROM $ll,
                $kkx4: calculate_quantity                 FROM $kk,
                $llx4: send_quantity                      FROM $ll,
                $kkx5: calculate_total_for_row            FROM $kk,
                $llx5: send_total_for_row                 FROM $ll,
                $kkx6: calculate_total_bill               FROM $kk,
                $llx6: send_total_bill                    FROM $ll,
                $kkx7: receive_error_confirmation_message FROM $kk,
                $llx7: receive_error_confirmation_message FROM $ll


        DO
                ADD $kkx1 PRECEDES $llx1;
                ADD $kkx2 PRECEDES $llx2;
                ADD $kkx3 PRECEDES $llx3;
                ADD $kkx4 PRECEDES $llx4;
                ADD $kkx5 PRECEDES $llx5;
                ADD $kkx6 PRECEDES $llx6;
                ADD $llx7 PRECEDES $kkx7;



        OD;
OD;

/* COORDINATE 20: Interaction between the User behaviors and TT/Merchandise ILF behaviors, and
nested COORDINATE with 15 ADDs representing 15 DETs */


COORDINATE              $mm: buy_product              FROM User,
        $nn: send_calculated_amount_to_purchasing     FROM TT_Merchandise_EIF

DO
```

COORDINATE

$mmx1: click_buy_button	FROM $mm,
$nnx1: receive_buy_button_prompt	FROM $nn,
$mmx2: receive_product	FROM $mm,
$nnx2: send_product	FROM $nn,
$mmx3: receive_price	FROM $mm,
$nnx3: send_price	FROM $nn,
$mmx4: receive_quantity	FROM $mm,
$nnx4: send_quantity	FROM $nn,
$mmx5: receive_row_total	FROM $mm,
$nnx5: send_row_total	FROM $nn,
$mmx6: receive_bill_total	FROM $mm,
$nnx6: send_bill_total	FROM $nn,
$mmx7: receive_cc_type	FROM $mm,
$nnx7: send_cc_type	FROM $nn,
$mmx8: receive_cc_number	FROM $mm,
$nnx8: send_cc_number	FROM $nn,
$mmx9: receive_expiration_date	FROM $mm,
$nnx9: send_expiration_date	FROM $nn,
$mmx10: receive_mailing_name	FROM $mm,
$nnx10: send_mailing_name	FROM $nn,
$mmx11: receive_address	FROM $mm,
$nnx11: send_address	FROM $nn,
$mmx12: receive_city	FROM $mm,
$nnx12: send_city	FROM $nn,
$mmx13: receive_state	FROM $mm,
$nnx13: send_state	FROM $nn,
$mmx14: receive_zip	FROM $mm,
$nnx14: send_zip	FROM $nn,
$mmx15: receive_error_confirmation_message	FROM $mm,
$nnx15: send_error_confirmation_message	FROM $nn

DO

ADD $mmx1 PRECEDES $nnx1;
ADD $mmx2 PRECEDES $nnx2;
ADD $mmx3 PRECEDES $nnx3;
ADD $mmx4 PRECEDES $nnx4;
ADD $mmx5 PRECEDES $nnx5;
ADD $mmx6 PRECEDES $nnx6;
ADD $mmx7 PRECEDES $nnx7;
ADD $mmx8 PRECEDES $nnx8;
ADD $mmx9 PRECEDES $nnx9;
ADD $mmx10 PRECEDES $nnx10;
ADD $mmx11 PRECEDES $nnx11;
ADD $mmx12 PRECEDES $nnx12;
ADD $mmx13 PRECEDES $nnx13;
ADD $mmx14 PRECEDES $nnx14;
ADD $nnx15 PRECEDES $mmx15;

```
        OD;
OD;


/* Data Function Calculation using SHARE ALL and assuming Average functional complexity and size rather than specific RET/DET calculation */

/* SHARE All 1 */
TT, GC_ILF SHARE ALL writing;

/* SHARE All 2 */
TT, Teetimes_ILF SHARE ALL writing;

/* SHARE All 3 */
TT, Scoreboard_ILF SHARE ALL writing;

/* SHARE All 4 */
TT, Merchandise_EIF SHARE ALL writing;
```

D. MP SCHEMA FOR COURSE OF ACTION 4

```
/*      Name: MP SCHEMA COA 4 Nested COORDINATEs for Data and Transactional      Functions.
        Purpose: The It's Tee Time example for UFP estimate is derived from the It's      TeeTime
        counting example, courtesy of Q/P Management Group. Tee Time source information is
        protected by copyright [56]. This example was refined and improvised by Monica Farah-
        Stapleton 06/20/16, and updated by Prof Mikhail Auguston, 06/22/16.
        Tool Used: MP Analyzed on Firebird
        Scope: 1            */

SCHEMA TeeTime_Nested COORDINATEs_Trans_Data

/* ROOT User: Behaviors executed by the User of the It's Tee Time application */

 ROOT User: (* ( (inquire_on_state_data
                              inquire_on_city_data
                              inquire_on_golfcourse_list
                              (* (inquire_on_golfcourse_detail | go_back )*)
                              inquire_on_reservation_display
                              (input_add_reservation_data |
 input_change_reservation_data |
 input_delete_reservation_data)
                                        inquire_on_maintain_golfcourses
                                        (input_add_maintain_golfcourses_data |
 input_change_maintain_golfcourses_data |
 input_delete_maintain_golfcourses_data) )
                              inquire_on_scoreboard_display
                               (input_add_scoreboard_data |
 input_change_scoreboard_data |
 input_delete_scoreboard_data)
                                        inquire_on_shopping_display
                                        (* (inquire_on_product_display
 calculate_total_amount
 buy_product )*)
                                                                                | exit)
                    *);

          inquire_on_state_data: click_state_arrow_dropdown receive_state_list_display;
          inquire_on_city_data: view_state_data_entered click_on_city_arrow_dropdown
          receive_city_list_display;

inquire_on_golfcourse_list: view_state_data_entered view_city_data_entered
          click_list_display_button view_golfcourse_name_displayed;

inquire_on_golfcourse_detail: click_icon_from_golfcourse_list request_id
          request_name    request_address  request_city      request_state     request_zip
          request_phone   request_description        request_slope     request_fees
          request_requirements;

inquire_on_reservation_display:    carryover_id                carryover_coursename
```

click_on_date_dropdown click_display request_time request_no_of_players
request_no_of_holes request_name request_cc_type request_cc_no
request_phone_no;

input_add_reservation_data: input_id input_coursename input_date
input_time
input_no_players input_no_holes input_name input_cc_type input_cc_no
input_phone_no click_add_button receive_error_confirmation_message;

input_change_reservation_data: input_change_id input_change_coursename
input_change_date input_change_time input_change_no_players
input_change_no_holes
input_change_name input_change_cc_type input_change_cc_no
input_change_phone_no click_change_button receive_error_confirmation_message;

input_delete_reservation_data: input_delete_id input_delete_coursename
input_delete_date input_delete_time click_delete_button
receive_error_confirmation_message;

inquire_on_maintain_golfcourses: enter_coursename click_display_button request_id
request_address request_city request_state request_zip request_phone
request_description request_slope request_fees request_requirements
receive_error_confirmation_message;

input_add_maintain_golfcourses_data: input_add_coursename input_add_address
input_add_city
input_add_state input_add_zip input_add_phone input_add_description
input_add_slope input_add_fees input_add_requirements click_add_button receive_id
receive_error_confirmation_message;

input_change_maintain_golfcourses_data: input_change_coursename input_change_address
input_change_city input_change_state input_change_zip
input_change_phone input_change_description input_change_slope
input_change_fees input_change_requirements click_change_button
receive_id receive_error_confirmation_message;

input_delete_maintain_golfcourses_data: input_delete_id click_delete_button
receive_error_confirmation_message;

inquire_on_scoreboard_display: click_scoreboard_icon request_name request_course
request_date request_slope request_score;

input_add_scoreboard_data: input_add_name input_add_course input_add_date
input_add_slope input_add_score click_add_button
receive_error_confirmation_message;

input_change_scoreboard_data: input_change_name input_change_course
input_change_date input_change_slope input_change_score
click_change_button receive_error_confirmation_message;

```
input_delete_scoreboard_data:                highlight_name                click_delete_button
        receive_error_confirmation_message;

inquire_on_shopping_display: click_teetime_shopping_icon   request_product  request_unit_price;

inquire_on_product_display: click_view_icon request_image receive_error_confirmation_message;

calculate_total_amount: enter_quantity calculate_price_action calculate_price
        calculate_quantity        calculate_total_for_row          calculate_total_bill
        receive_error_confirmation_message;

buy_product: click_buy_button     receive_product  receive_price     receive_quantity
        receive_row_total         receive_bill_total receive_cc_type  receive_cc_number
        receive_expiration_date   receive_mailing_name    receive_address          receive_city
        receive_state receive_zip  receive_error_confirmation_message;



/* ROOT TT_GC_ILF: The combined, relevant behaviors of the IAA and Golfcourses ILF */

ROOT TT_GC_ILF: (* (get_state_result
                                get_city_result
                                get_golfcourse_list_result
                                get_golfcourse_detail_result
                                get_maintain_golfcourses_result
                                (*(add_maintain_golfcourses_data |
                change_maintain_golfcourses_data |
                delete_maintain_golfcourses_data)*) )


                        *);

get_state_result: receive_state_arrow_prompt send_state_list_display;

get_city_result: send_state_data_entered receive_city_arrow_prompt
        send_city_list_display;

get_golfcourse_list_result: send_state_data_entered send_city_data_entered
        receive_list_display_button_prompt send_golfcourse_name_displayed;

get_golfcourse_detail_result:       get_golfcourse_detail_results     send_id
        send_name       send_address    send_city       send_state      send_zip
        send_phone      send_description        send_slope      send_fees
        send_requirements;

get_maintain_golfcourses_result: view_coursename receive_display_button_prompt    send_id
        send_address send_city send_state        send_zip        send_phone      send_description
        send_slope send_fees send_requirements   send_error_confirmation_message;
```

```
add_maintain_golfcourses_data: add_coursename    add_address       add_city
        add_state        add_zip          add_phone        add_description  add_slope
        add_fees add_requirements         receive_add_button_prompt        send_id
        send_error_confirmation_message;

change_maintain_golfcourses_data: change_coursename      change_address  change_city
        change_state     change_zip       change_phone    change_description        change_slope
        change_fees change_requirements receive_change_button_prompt    send_id
        send_error_confirmation_message;


delete_maintain_golfcourses_data: delete_id          receive_delete_button_prompt
        send_error_confirmation_message;




/* ROOT TT_Teetimes_ILF: The combined, relevant behaviors of the IAA and Teetimes ILF */

ROOT TT_Teetimes_ILF: ( get_reservation_display_result
                                (*(add_reservation_data
                                        | change_reservation_data
                                                | delete_reservation_data)*)
                                );


get_reservation_display_result:     display_id          display_coursename       display_date
        send_display_results       send_time send_no_of_players     send_no_of_holes
        send_name       send_cc_type     send_cc_no       send_phone_no;

add_reservation_data: add_id       add_coursename add_date          add_time
        add_no_players  add_no_holes     add_name        add_cc_type              add_cc_no

        add_phone_no receive_add_button_response        send_error_confirmation_message;


change_reservation_data: change_id          change_coursename
        change_date      change_time      change_no_players        change_no_holes
        change_name      change_cc_type  change_cc_no
        change_phone_no                                           receive_change_button_response
        send_error_confirmation_message;

delete_reservation_data: delete_id          delete_coursename
        delete_date      delete_time      receive_delete_button_response
        send_error_confirmation_message;



/* ROOT TT_Scoreboard_ILF: The combined, relevant behaviors of the IAA and Scoreboard ILF */
```

```
ROOT TT_Scoreboard_ILF: ( get_scoreboard_display_result
                                    (*(add_scoreboard_data
                                                | change_scoreboard_data
                                                        | delete_scoreboard_data)*)
                                    );


get_scoreboard_display_result: receive_scoreboard_icon_prompt       send_name        send_course
        send_date        send_slope        send_score;

add_scoreboard_data: add_name  add_course        add_date add_slope add_score
        receive_add_button_response              send_error_confirmation_message;

change_scoreboard_data: change_name     change_course    change_date       change_slope
        change_score      receive_change_button_response send_error_confirmation_message;

delete_scoreboard_data:                 delete_name                  receive_delete_button_prompt
        send_error_confirmation_message;


/* ROOT TT_Merchandise_EIF: The combined, relevant behaviors of the IAA and Merchandise EIF */

ROOT TT_Merchandise_EIF: ( get_shopping_display_result
                                    (*(get_product_display_result get_calculated_total_amount
                                    send_calculated_amount_to_purchasing)*)
                                    );

get_shopping_display: receive_teetime_shopping_icon_prompt        send_product
                        send_unit_price;

get_product_display: receive_view_icon_prompt      send_image
                send_error_confirmation_message;

get_calculated_total_amount:       receive_quantity  receive_calculate_price_action_prompt
        send_price        send_quantity send_total_for_row  send_total_bill
        send_error_confirmation_message;

send_calculated_amount_to_purchasing: receive_buy_button_prompt          send_product
        send_price        send_quantity     send_row_total   send_bill_total          send_cc_type
        send_cc_number send_expiration_date      send_mailing_name              send_address
        send_city                 send_state                send_zip
        send_error_confirmation_message;




/* COORDINATE 1: Interaction between the User behaviors and TT/Golfcourses ILF behaviors , and nested
COORDINATE with 2 ADDs representing 2 DETs */

COORDINATE $a:inquire_on_state_data              FROM User,
```

```
                $b:get_state_result             FROM TT_GC_ILF

DO

                COORDINATE

                $ax: click_state_arrow_dropdown     FROM $a,
                $bx: receive_state_arrow_prompt     FROM $b,
                $axx: receive_state_list_display    FROM $a,
                $bxx: send_state_list_display       FROM $b
        DO


                ADD $ax PRECEDES $bx;
                ADD $bxx PRECEDES $axx;
        OD;
OD;


/* COORDINATE 2: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 3 ADDs representing 3 DETs*/

COORDINATE $c:inquire_on_city_data                  FROM User,
                $d:get_city_result              FROM TT_GC_ILF

DO

                COORDINATE

                        $cx1: view_state_data_entered       FROM $c,
                        $dx1: send_state_data_entered       FROM $d,
                        $cx2: click_on_city_arrow_dropdown  FROM $c,
                        $dx2: receive_city_arrow_prompt     FROM $d,
                        $cx3: receive_city_list_display     FROM $c,
                        $dx3: send_city_list_display        FROM $d

        DO
                ADD $cx1 PRECEDES $dx1;
                ADD $cx2 PRECEDES $dx2;
                ADD $dx3 PRECEDES $cx3;

        OD;
OD;


/* COORDINATE 3: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 4 ADDs representing 4 DETs */

COORDINATE $e:inquire_on_golfcourse_list             FROM User,
                $f:get_golfcourse_list_result       FROM TT_GC_ILF
```

```
DO

COORDINATE
                        $ex1: view_state_data_entered                   FROM $e,
                        $fx1: send_state_data_entered                   FROM $f,
                        $ex2: view_city_data_entered                    FROM $e,
                        $fx2: send_city_data_entered                    FROM $f,
                        $ex3: click_list_display_button                 FROM $e,
                        $fx3: receive_list_display_button_prompt        FROM $f,
                        $ex4: view_golfcourse_name_displayed            FROM $e,
                        $fx4: send_golfcourse_name_displayed            FROM $f

        DO
                ADD $ex1 PRECEDES $fx1;
                ADD $ex2 PRECEDES $fx2;
                ADD $ex3 PRECEDES $fx3;
                ADD $fx4 PRECEDES $ex4;

        OD;
OD;



/* COORDINATE 4: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 12 ADDs representing 12 DETs */

COORDINATE $g: inquire_on_golfcourse_detail             FROM User,
               $h: get_golfcourse_detail_result         FROM TT_GC_ILF

DO

COORDINATE


                $gx1: click_icon_from_golfcourse_list           FROM $g,
                $hx1: get_golfcourse_detail_results             FROM $h,
                $gx2: request_id                                FROM $g,
                $hx2: send_id                                   FROM $h,
                $gx3: request_name                              FROM $g,
                $hx3: send_name                                 FROM $h,
                $gx4: request_address                           FROM $g,
                $hx4: send_address                              FROM $h,
                $gx5: request_city                              FROM $g,
                $hx5: send_city                                 FROM $h,
                $gx6: request_state                             FROM $g,
                $hx6: send_state                                FROM $h,
                $gx7: request_zip                               FROM $g,
                $hx7: send_zip                                  FROM $h,
                $gx8: request_phone                             FROM $g,
```

```
            $hx8: send_phone                    FROM $h,
            $gx9: request_description           FROM $g,
            $hx9: send_description              FROM $h,
            $gx10: request_slope                FROM $g,
            $hx10: send_slope                   FROM $h,
            $gx11: request_fees                 FROM $g,
            $hx11: send_fees                    FROM $h,
            $gx12: request_requirements         FROM $g,
            $hx12: send_requirements            FROM $h

        DO
            ADD $gx1 PRECEDES $hx1;
            ADD $gx2 PRECEDES $hx2;
            ADD $gx3 PRECEDES $hx3;
            ADD $gx4 PRECEDES $hx4;
            ADD $gx5 PRECEDES $hx5;
            ADD $gx6 PRECEDES $hx6;
            ADD $gx7 PRECEDES $hx7;
            ADD $gx8 PRECEDES $hx8;
            ADD $gx9 PRECEDES $hx9;
            ADD $gx10 PRECEDES $hx10;
            ADD $gx11 PRECEDES $hx11;
            ADD $hx12 PRECEDES $gx12;


        OD;
OD;


/* COORDINATE 5: Interaction between the User behaviors and TT/Teetimes ILF behaviors, and nested
COORDINATE with 11 ADDs representing 11 DETs */

COORDINATE $i:inquire_on_reservation_display     FROM User,
            $j:get_reservation_display_result    FROM TT_Teetimes_ILF

        DO

        COORDINATE


            $ix1: carryover_id                  FROM $i,
            $jx1: display_id                    FROM $j,
            $ix2: carryover_coursename          FROM $i,
            $jx2: display_coursename            FROM $j,
            $ix3: click_on_date_dropdown        FROM $i,
            $jx3: display_date                  FROM $j,
            $ix4: click_display                 FROM $i,
            $jx4: send_display_results          FROM $j,
            $ix5: request_time                  FROM $i,
            $jx5: send_time                     FROM $j,
            $ix6: request_no_of_players         FROM $i,
```

```
                $jx6: send_no_of_players                FROM $j,
                $ix7: request_no_of_holes               FROM $i,
                $jx7: send_no_of_holes                  FROM $j,
                $ix8: request_name                      FROM $i,
                $jx8: send_name                         FROM $j,
                $ix9: request_cc_type                   FROM $i,
                $jx9: send_cc_type                      FROM $j,
                $ix10: request_cc_no                    FROM $i,
                $jx10: send_cc_no                       FROM $j,
                $ix11: request_phone_no                 FROM $i,
                $jx11: send_phone_no                    FROM $j

        DO
                ADD $ix1 PRECEDES $jx1;
                ADD $ix2 PRECEDES $jx2;
                ADD $ix3 PRECEDES $jx3;
                ADD $ix4 PRECEDES $jx4;
                ADD $ix5 PRECEDES $jx5;
                ADD $ix6 PRECEDES $jx6;
                ADD $ix7 PRECEDES $jx7;
                ADD $ix8 PRECEDES $jx8;
                ADD $ix9 PRECEDES $jx9;
                ADD $ix10 PRECEDES $jx10;
                ADD $jx11 PRECEDES $ix11;


        OD;
OD;


/* COORDINATE 6: Interaction between the User behaviors and TT/Teetimes ILF behaviors and nested
COORDINATE with 12 ADDs representing 12 DETs */

COORDINATE $k: input_add_reservation_data                FROM User,
                $l:add_reservation_data             FROM TT_Teetimes_ILF
DO

        COORDINATE

                $kx1: input_id                          FROM $k,
                $lx1: add_id                            FROM $l,
                $kx2: input_coursename                  FROM $k,
                $lx2: add_coursename                    FROM $l,
                $kx3: input_date                        FROM $k,
                $lx3: add_date                          FROM $l,
                $kx4: input_time                        FROM $k,
                $lx4: add_time                          FROM $l,
                $kx5: input_no_players                  FROM $k,
                $lx5: add_no_players                    FROM $l,
                $kx6: input_no_holes                    FROM $k,
                $lx6: add_no_holes                      FROM $l,
```

```
                $kx7: input_name                                FROM $k,
                $lx7: add_name                                  FROM $l,
                $kx8: input_cc_type                             FROM $k,
                $lx8: add_cc_type                               FROM $l,
                $kx9: input_cc_no                               FROM $k,
                $lx9: add_cc_no                                 FROM $l,
                $kx10: input_phone_no                           FROM $k,
                $lx10: add_phone_no                             FROM $l,
                $kx11: click_add_button                         FROM $k,
                $lx11: receive_add_button_response              FROM $l,
                $kx12: receive_error_confirmation_message       FROM $k,
                $lx12: send_error_confirmation_message          FROM $l

        DO


                ADD $kx1 PRECEDES $lx1;
                ADD $kx2 PRECEDES $lx2;
                ADD $kx3 PRECEDES $lx3;
                ADD $kx4 PRECEDES $lx4;
                ADD $kx5 PRECEDES $lx5;
                ADD $kx6 PRECEDES $lx6;
                ADD $kx7 PRECEDES $lx7;
                ADD $kx8 PRECEDES $lx8;
                ADD $kx9 PRECEDES $lx9;
                ADD $kx10 PRECEDES $lx10;
                ADD $kx11 PRECEDES $lx11;
                ADD $lx12 PRECEDES $kx12;


        OD;
OD;


/* COORDINATE 7: Interaction between the User behaviors and TT/Teetimes ILF behaviors, and nested
COORDINATE with 12 ADDs representing 12 DETs */

COORDINATE $m: input_change_reservation_data     FROM User,
                $n:change_reservation_data              FROM TT_Teetimes_ILF

DO

        COORDINATE

                $mx1: input_change_id                   FROM $m,
                $nx1: change_id                         FROM $n,
                $mx2: input_change_coursename           FROM $m,
                $nx2: change_coursename                 FROM $n,
                $mx3: input_change_date                 FROM $m,
                $nx3: change_date                       FROM $n,
                $mx4: input_change_time                 FROM $m,
```

```
                $nx4: change_time                          FROM $n,
                $mx5: input_change_no_players              FROM $m,
                $nx5: change_no_players                    FROM $n,
                $mx6: input_change_no_holes                FROM $m,
                $nx6: change_no_holes                      FROM $n,
                $mx7: input_change_name                    FROM $m,
                $nx7: change_name                          FROM $n,
                $mx8: input_change_cc_type                 FROM $m,
                $nx8: change_cc_type                       FROM $n,
                $mx9: input_change_cc_no                   FROM $m,
                $nx9: change_cc_no                         FROM $n,
                $mx10: input_change_phone_no               FROM $m,
                $nx10: change_phone_no                     FROM $n,
                $mx11: click_change_button                 FROM $m,
                $nx11: receive_change_button_response      FROM $n,
                $mx12: receive_error_confirmation_message        FROM $m,
                $nx12: send_error_confirmation_message           FROM $n

        DO


                ADD $mx1 PRECEDES $nx1;
                ADD $mx2 PRECEDES $nx2;
                ADD $mx3 PRECEDES $nx3;
                ADD $mx4 PRECEDES $nx4;
                ADD $mx5 PRECEDES $nx5;
                ADD $mx6 PRECEDES $nx6;
                ADD $mx7 PRECEDES $nx7;
                ADD $mx8 PRECEDES $nx8;
                ADD $mx9 PRECEDES $nx9;
                ADD $mx10 PRECEDES $nx10;
                ADD $mx11 PRECEDES $nx11;
                ADD $nx12 PRECEDES $mx12;
        OD;
OD;



/* COORDINATE 8: Interaction between the User behaviors and TT/Teetimes ILF behaviors, and nested
COORDINATE with 6 ADDs representing 6 DETs */

COORDINATE $o:input_delete_reservation_data FROM User,
                $p:delete_reservation_data                FROM TT_Teetimes_ILF
DO

        COORDINATE

                $ox1: input_delete_id                              FROM $o,
                $px1: delete_id                                    FROM $p,
                $ox2: input_delete_coursename                      FROM $o,
```

```
                $px2: delete_coursename                 FROM $p,
                $ox3: input_delete_date                 FROM $o,
                $px3: delete_date                       FROM $p,
                $ox4: input_delete_time                 FROM $o,
                $px4: delete_time                       FROM $p,
                $ox5: click_delete_button               FROM $o,
                $px5: receive_delete_button_response    FROM $p,
                $ox6: receive_error_confirmation_message FROM $o,
                $px6: send_error_confirmation_message   FROM $p

        DO
                ADD $ox1 PRECEDES $px1;
                ADD $ox2 PRECEDES $px2;
                ADD $ox3 PRECEDES $px3;
                ADD $ox4 PRECEDES $px4;
                ADD $ox5 PRECEDES $px5;
                ADD $px6 PRECEDES $ox6;
        OD;
OD;


/* COORDINATE 9: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and nested
COORDINATE with 13 ADDs representing 13 DETs */

COORDINATE $q:inquire_on_maintain_golfcourses            FROM User,
                $r:get_maintain_golfcourses_result       FROM TT_GC_ILF

        DO

        COORDINATE

                $qx1: enter_coursename                  FROM $q,
                $rx1: view_coursename                   FROM $r,
                $qx2: click_display_button              FROM $q,
                $rx2: receive_display_button_prompt     FROM $r,
                $qx3: request_id                        FROM $q,
                $rx3: send_id                           FROM $r,
                $qx4: request_address                   FROM $q,
                $rx4: send_address                      FROM $r,
                $qx5: request_city                      FROM $q,
                $rx5: send_city                         FROM $r,
                $qx6: request_state                     FROM $q,
                $rx6: send_state                        FROM $r,
                $qx7: request_zip                       FROM $q,
                $rx7: send_zip                          FROM $r,
                $qx8: request_phone                     FROM $q,
                $rx8: send_phone                        FROM $r,
                $qx9: request_description               FROM $q,
                $rx9: send_description                  FROM $r,
                $qx10: request_slope                    FROM $q,
```

```
                $rx10: send_slope                                   FROM $r,
                $qx11: request_fees                                 FROM $q,
                $rx11: send_fees                                    FROM $r,
                $qx12: request_requirements                         FROM $q,
                $rx12: send_requirements                            FROM $r,
                $qx13: receive_error_confirmation_message           FROM $q,
                $rx13: send_error_confirmation_message              FROM $r


        DO
                ADD $qx1 PRECEDES $rx1;
                ADD $qx2 PRECEDES $rx2;
                ADD $qx3 PRECEDES $rx3;
                ADD $qx4 PRECEDES $rx4;
                ADD $qx5 PRECEDES $rx5;
                ADD $qx6 PRECEDES $rx6;
                ADD $qx7 PRECEDES $rx7;
                ADD $qx8 PRECEDES $rx8;
                ADD $qx9 PRECEDES $rx9;
                ADD $qx10 PRECEDES $rx10;
                ADD $qx11 PRECEDES $rx11;
                ADD $qx12 PRECEDES $rx12;
                ADD $rx13 PRECEDES $qx13;


        OD;
OD;


/* COORDINATE 10: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and
nested COORDINATE with 13 ADDs representing 13 DETs */

COORDINATE $s:input_add_maintain_golfcourses_data           FROM User,
                $t:add_maintain_golfcourses_data            FROM TT_GC_ILF
        DO

        COORDINATE

                $sx1: input_add_coursename                  FROM $s,
                $tx1: add_coursename                        FROM $t,
                $sx2: input_add_address                     FROM $s,
                $tx2: add_address                           FROM $t,
                $sx3: input_add_city                        FROM $s,
                $tx3: add_city                              FROM $t,
                $sx4: input_add_state                       FROM $s,
                $tx4: add_state                             FROM $t,
                $sx5: input_add_zip                         FROM $s,
                $tx5: add_zip                               FROM $t,
                $sx6: input_add_phone                       FROM $s,
```

```
                $tx6: add_phone                                 FROM $t,
                $sx7: input_add_description                     FROM $s,
                $tx7: add_description                           FROM $t,
                $sx8: input_add_slope                           FROM $s,
                $tx8: add_slope                                 FROM $t,
                $sx9: input_add_fees                            FROM $s,
                $tx9: add_fees                                  FROM $t,
                $sx10: input_add_requirements                   FROM $s,
                $tx10: add_requirements                         FROM $t,
                $sx11: click_add_button                         FROM $s,
                $tx11: receive_add_button_prompt                FROM $t,
                $sx12: receive_id                               FROM $s,
                $tx12: send_id                                  FROM $t,
                $sx13: receive_error_confirmation_message       FROM $s,
                $tx13: send_error_confirmation_message          FROM $t

        DO
                ADD $sx1 PRECEDES $tx1;
                ADD $sx2 PRECEDES $tx2;
                ADD $sx3 PRECEDES $tx3;
                ADD $sx4 PRECEDES $tx4;
                ADD $sx5 PRECEDES $tx5;
                ADD $sx6 PRECEDES $tx6;
                ADD $sx7 PRECEDES $tx7;
                ADD $sx8 PRECEDES $tx8;
                ADD $sx9 PRECEDES $tx9;
                ADD $sx10 PRECEDES $tx10;
                ADD $sx11 PRECEDES $tx11;
                ADD $tx12 PRECEDES $sx12;
                ADD $tx13 PRECEDES $sx13;

        OD;
OD;


/* COORDINATE 11: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and
nested COORDINATE with 13 ADDs representing 13 DETs */

COORDINATE $u:input_change_maintain_golfcourses_data    FROM User,
                $v:change_maintain_golfcourses_data             FROM TT_GC_ILF

        DO

        COORDINATE

                $ux1: input_change_coursename                   FROM $u,
                $vx1: change_coursename                         FROM $v,
                $ux2: input_change_address                      FROM $u,
                $vx2: change_address                            FROM $v,
                $ux3: input_change_city                         FROM $u,
                $vx3: change_city                               FROM $v,
```

```
                $ux4: input_change_state                    FROM $u,
                $vx4: change_state                          FROM $v,
                $ux5: input_change_zip                      FROM $u,
                $vx5: change_zip                            FROM $v,
                $ux6: input_change_phone                    FROM $u,
                $vx6: change_phone                          FROM $v,
                $ux7: input_change_description              FROM $u,
                $vx7: change_description                    FROM $v,
                $ux8: input_change_slope                    FROM $u,
                $vx8: change_slope                          FROM $v,
                $ux9: input_change_fees                     FROM $u,
                $vx9: change_fees                           FROM $v,
                $ux10: input_change_requirements            FROM $u,
                $vx10: change_requirements                  FROM $v,
                $ux11: click_change_button                  FROM $u,
                $vx11: receive_change_button_prompt         FROM $v,
                $ux12: receive_id                           FROM $u,
                $vx12: send_id                              FROM $v,
                $ux13: receive_error_confirmation_message   FROM $u,
                $vx13: send_error_confirmation_message      FROM $v


        DO
                ADD $ux1 PRECEDES $vx1;
                ADD $ux2 PRECEDES $vx2;
                ADD $ux3 PRECEDES $vx3;
                ADD $ux4 PRECEDES $vx4;
                ADD $ux5 PRECEDES $vx5;
                ADD $ux6 PRECEDES $vx6;
                ADD $ux7 PRECEDES $vx7;
                ADD $ux8 PRECEDES $vx8;
                ADD $ux9 PRECEDES $vx9;
                ADD $ux10 PRECEDES $vx10;
                ADD $ux11 PRECEDES $vx11;
                ADD $vx12 PRECEDES $ux12;
                ADD $vx13 PRECEDES $ux13;


        OD;
OD;


/* COORDINATE 12: Interaction between the User behaviors and TT/Golfcourses ILF behaviors, and
nested COORDINATE with 3 ADDs representing 3 DETs */

COORDINATE $w:input_delete_maintain_golfcourses_data        FROM User,
                $x:delete_maintain_golfcourses_data         FROM TT_GC_ILF

DO
```

```
        COORDINATE

                $wx1: input_delete_id                       FROM $w,
                $xx1: delete_id                             FROM $x,
                $wx2: click_delete_button                   FROM $w,
                $xx2: receive_delete_button_prompt          FROM $x,
                $wx3: input_change_city                     FROM $w,
                $xx3: change_city                           FROM $x



        DO
                ADD $wx1 PRECEDES $xx1;
                ADD $xx2 PRECEDES $wx2;
                ADD $xx3 PRECEDES $wx3;


        OD;
OD;


/* COORDINATE 13: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 6 ADDs representing 6 DETs */

COORDINATE $y: inquire_on_scoreboard_display        FROM User,
                $z: get_scoreboard_display_result   FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $yx1: click_scoreboard_icon                 FROM $y,
                $zx1: receive_scoreboard_icon_prompt        FROM $z,
                $yx2: request_name                          FROM $y,
                $zx2: send_name                             FROM $z,
                $yx3: request_course                        FROM $y,
                $zx3: send_course                           FROM $z,
                $yx4: request_date                          FROM $y,
                $zx4: send_date                             FROM $z,
                $yx5: request_slope                         FROM $y,
                $zx5: send_slope                            FROM $z,
                $yx6: request_score                         FROM $y,
                $zx6: send_score                            FROM $z

        DO
                ADD $yx1 PRECEDES $zx1;
                ADD $yx2 PRECEDES $zx2;
                ADD $yx3 PRECEDES $zx3;
                ADD $yx4 PRECEDES $zx4;
                ADD $yx5 PRECEDES $zx5;
```

```
                ADD $yx6 PRECEDES $zx6;

        OD;
OD;


/* COORDINATE 14: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 7 ADDs representing 7 DETs */


COORDINATE $aa: input_add_scoreboard_data                FROM User,
                $bb: add_scoreboard_data                 FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $aax1: input_add_name                    FROM $aa,
                $bbx1: add_name                          FROM $bb,
                $aax2: input_add_course                  FROM $aa,
                $bbx2: add_course                        FROM $bb,
                $aax3: input_add_date                    FROM $aa,
                $bbx3: add_date                          FROM $bb,
                $aax4: input_add_slope                   FROM $aa,
                $bbx4: add_slope                         FROM $bb,
                $aax5: input_add_score                   FROM $aa,
                $bbx5: add_score                         FROM $bb,
                $aax6: click_add_button                  FROM $aa,
                $bbx6: receive_add_button_response       FROM $bb,
                $aax7: receive_error_confirmation_message FROM $aa,
                $bbx7: send_error_confirmation_message   FROM $bb


        DO
                ADD $aax1 PRECEDES $bbx1;
                ADD $aax2 PRECEDES $bbx2;
                ADD $aax3 PRECEDES $bbx3;
                ADD $aax4 PRECEDES $bbx4;
                ADD $aax5 PRECEDES $bbx5;
                ADD $aax6 PRECEDES $bbx6;
                ADD $aax7 PRECEDES $bbx7;

        OD;
OD;


/* COORDINATE 15: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 7 ADDs representing 7 DETs */


COORDINATE $cc: input_change_scoreboard_data     FROM User,
```

```
                $dd: change_scoreboard_data          FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $ccx1: input_change_name                        FROM $cc,
                $ddx1: change_name                              FROM $dd,
                $ccx2: input_change_course                      FROM $cc,
                $ddx2: change_course                            FROM $dd,
                $ccx3: input_change_date                        FROM $cc,
                $ddx3: change_date                              FROM $dd,
                $ccx4: input_change_slope                       FROM $cc,
                $ddx4: change_slope                             FROM $dd,
                $ccx5: input_change_score                       FROM $cc,
                $ddx5: change_score                             FROM $dd,
                $ccx6: click_change_button                      FROM $cc,
                $ddx6: receive_change_button_response           FROM $dd,
                $ccx7: receive_error_confirmation_message       FROM $cc,
                $ddx7: send_error_confirmation_message          FROM $dd


        DO
                ADD $ccx1 PRECEDES $ddx1;
                ADD $ccx2 PRECEDES $ddx2;
                ADD $ccx3 PRECEDES $ddx3;
                ADD $ccx4 PRECEDES $ddx4;
                ADD $ccx5 PRECEDES $ddx5;
                ADD $ccx6 PRECEDES $ddx6;
                ADD $ccx7 PRECEDES $ddx7;

        OD;
OD;


/* COORDINATE 16: Interaction between the User behaviors and TT/Scoreboard ILF behaviors, and nested
COORDINATE with 3 ADDs representing 3 DETs */

COORDINATE $ee: input_delete_scoreboard_data         FROM User,
                $ff: delete_scoreboard_data          FROM TT_Scoreboard_ILF

DO

        COORDINATE

                $eex1: highlight_name                           FROM $ee,
                $ffx1: delete_name                              FROM $ff,
                $eex2: click_delete_button                      FROM $ee,
                $ffx2: receive_delete_button_prompt             FROM $ff,
                $eex3: receive_error_confirmation_message       FROM $ee,
                $ffx3: send_error_confirmation_message          FROM $ff
```

```
        DO
                ADD $eex1 PRECEDES $ffx1;
                ADD $eex2 PRECEDES $ffx2;
                ADD $ffx3 PRECEDES $eex3;

        OD;
OD;
```

/* COORDINATE 17: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and nested COORDINATE with 3 ADDs representing 3 DETs */

```
COORDINATE $gg: inquire_on_shopping_display                 FROM User,
                $hh: get_shopping_display_result            FROM TT_Merchandise_EIF

DO

        COORDINATE

                $ggx1: click_teetime_shopping_icon                  FROM $gg,
                $hhx1: receive_teetime_shopping_icon_prompt         FROM $hh,
                $ggx2: request_product                              FROM $gg,
                $hhx2: send_product                                 FROM $hh,
                $ggx3: request_unit_price                           FROM $gg,
                $hhx3: send_unit_price                              FROM $hh



        DO
                ADD $ggx1 PRECEDES $hhx1;
                ADD $ggx2 PRECEDES $hhx2;
                ADD $hhx3 PRECEDES $ggx3;

        OD;
OD;
```

/* COORDINATE 18: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and nested COORDINATE with 3 ADDs representing 3 DETs */

```
COORDINATE $ii:inquire_on_product_display            FROM User,
                $jj:get_product_display_result       FROM TT_Merchandise_EIF

DO
```

```
        COORDINATE

                $iix1: click_view_icon                          FROM $ii,
                $jjx1: receive_view_icon_prompt                 FROM $jj,
                $iix2: request_image                            FROM $ii,
                $jjx2: send_image                               FROM $jj,
                $iix3: receive_error_confirmation_message       FROM $ii,
                $jjx3: send_error_confirmation_message          FROM $jj


        DO
                ADD $iix1 PRECEDES $jjx1;
                ADD $iix2 PRECEDES $jjx2;
                ADD $jjx3 PRECEDES $iix3;

        OD;
OD;


/* COORDINATE 19: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and
nested COORDINATE with 7 ADDs representing 7 DETs */

COORDINATE $kk: calculate_total_amount          FROM User,
        $ll:get_calculated_total_amount         FROM TT_Merchandise_EIF

DO

        COORDINATE

                $kkx1: enter_quantity                           FROM $kk,
                $llx1: receive_quantity                         FROM $ll,
                $kkx2: calculate_price_action                   FROM $kk,
                $llx2: receive_calculate_price_action_prompt    FROM $ll,
                $kkx3: calculate_price                          FROM $kk,
                $llx3: send_price                               FROM $ll,
                $kkx4: calculate_quantity                       FROM $kk,
                $llx4: send_quantity                            FROM $ll,
                $kkx5: calculate_total_for_row                  FROM $kk,
                $llx5: send_total_for_row                       FROM $ll,
                $kkx6: calculate_total_bill                     FROM $kk,
                $llx6: send_total_bill                          FROM $ll,
                $kkx7: receive_error_confirmation_message       FROM $kk,
                $llx7: receive_error_confirmation_message       FROM $ll


        DO
                ADD $kkx1 PRECEDES $llx1;
                ADD $kkx2 PRECEDES $llx2;
```

```
                ADD $kkx3 PRECEDES $llx3;
                ADD $kkx4 PRECEDES $llx4;
                ADD $kkx5 PRECEDES $llx5;
                ADD $kkx6 PRECEDES $llx6;
                ADD $llx7 PRECEDES $kkx7;



        OD;
OD;


/* COORDINATE 20: Interaction between the User behaviors and TT/Merchandise EIF behaviors, and
nested COORDINATE with 15 ADDs representing 15 DETs */


COORDINATE      $mm: buy_product                        FROM User,
        $nn: send_calculated_amount_to_purchasing       FROM TT_Merchandise_EIF

DO

        COORDINATE

                $mmx1: click_buy_button                 FROM $mm,
                $nnx1: receive_buy_button_prompt        FROM $nn,
                $mmx2: receive_product                  FROM $mm,
                $nnx2: send_product                     FROM $nn,
                $mmx3: receive_price                    FROM $mm,
                $nnx3: send_price                       FROM $nn,
                $mmx4: receive_quantity                 FROM $mm,
                $nnx4: send_quantity                    FROM $nn,
                $mmx5: receive_row_total                FROM $mm,
                $nnx5: send_row_total                   FROM $nn,
                $mmx6: receive_bill_total               FROM $mm,
                $nnx6: send_bill_total                  FROM $nn,
                $mmx7: receive_cc_type                  FROM $mm,
                $nnx7: send_cc_type                     FROM $nn,
                $mmx8: receive_cc_number                FROM $mm,
                $nnx8: send_cc_number                   FROM $nn,
                $mmx9: receive_expiration_date          FROM $mm,
                $nnx9: send_expiration_date             FROM $nn,
                $mmx10: receive_mailing_name            FROM $mm,
                $nnx10: send_mailing_name               FROM $nn,
                $mmx11: receive_address                 FROM $mm,
                $nnx11: send_address                    FROM $nn,
                $mmx12: receive_city                    FROM $mm,
                $nnx12: send_city                       FROM $nn,
                $mmx13: receive_state                   FROM $mm,
                $nnx13: send_state                      FROM $nn,
                $mmx14: receive_zip                     FROM $mm,
```

```
                $nnx14: send_zip                                    FROM $nn,
                $mmx15: receive_error_confirmation_message          FROM $mm,
                $nnx15: send_error_confirmation_message             FROM $nn

        DO
                ADD $mmx1 PRECEDES $nnx1;
                ADD $mmx2 PRECEDES $nnx2;
                ADD $mmx3 PRECEDES $nnx3;
                ADD $mmx4 PRECEDES $nnx4;
                ADD $mmx5 PRECEDES $nnx5;
                ADD $mmx6 PRECEDES $nnx6;
                ADD $mmx7 PRECEDES $nnx7;
                ADD $mmx8 PRECEDES $nnx8;
                ADD $mmx9 PRECEDES $nnx9;
                ADD $mmx10 PRECEDES $nnx10;
                ADD $mmx11 PRECEDES $nnx11;
                ADD $mmx12 PRECEDES $nnx12;
                ADD $mmx13 PRECEDES $nnx13;
                ADD $mmx14 PRECEDES $nnx14;
                ADD $nnx15 PRECEDES $mmx15;


        OD;
OD;

/* Data Function Calculation using COORDINATEs */

/* ROOT TT: The relevant behaviors of the IAA */

ROOT TT: ( * (request | no_action ) * );

request: request_GC_id              request_GC_coursename  request_GC_address
request_GC_city          request_GC_state          request_GC_zip          request_GC_phone
        request_GC_description  request_GC_slope                request_GC_fees
        request_GC_requirements

        request_TT_id              request_TT_coursename  request_TT_date_repeating
        request_TT_teetime         request_TT_no_players
        request_TT_no_holes              request_TT_golfer_name  request_TT_credit_card_type
        request_TT_credit_card_number  request_TT_phone_number

        request_scoreboard_golfer_name          request_scoreboard_coursename
        request_scoreboard_date          request_scoreboard_slope
        request_scoreboard_score


        request_Merch_product_name          request_Merch_price      request_Merch_picture;
```

```
/* ROOT GC_ILF: The relevant behaviors of the Golfcourses ILF */

ROOT GC_ILF: (*( respond | no_action)*);

respond: respond_GC_id   respond_GC_coursename          respond_GC_address
respond_GC_city          respond_GC_state        respond_GC_zip                  respond_GC_phone
        respond_GC_description          respond_GC_slope                        respond_GC_fees
        respond_GC_requirements;


/* ROOT Teetimes_ILF: The relevant behaviors of the Teetimes ILF */

ROOT Teetimes_ILF: (*( respond1 | no_action)* );
respond1: respond_TT_id             respond_TT_coursename
respond_TT_date_repeating          respond_TT_teetime
respond_TT_no_players respond_TT_no_holes                  respond_TT_golfer_name
respond_TT_credit_card_type       respond_TT_credit_card_number
respond_TT_phone_number;


/* ROOT Scoreboard_ILF: The relevant behaviors of the Scoreboard ILF */

ROOT Scoreboard_ILF: (* ( respond2 | no_action) *);
respond2: respond_scoreboard_golfer_name          respond_scoreboard_coursename
        respond_scoreboard_daterespond_scoreboard_slope          respond_scoreboard_score;


/* ROOT Merchandise_EIF: The relevant behaviors of the Merchandise EIF */
ROOT Merchandise_EIF: (*(respond3 | no action)*);
respond3: respond_Merch_product_name   respond_Merch_price
respond_Merch_picture;



/* COORDINATE 21: Interaction between the TT IAA and the Golf Courses ILF, and nested COORDINATE
with 11 ADDs representing 11 DETs */


COORDINATE              $oo: request                    FROM TT,
                        $pp: respond                    FROM GC_ILF

DO

        COORDINATE

                $oox1: request_GC_id                    FROM $oo,
                $ppx1: respond_GC_id                    FROM $pp,
                $oox2: request_GC_coursename            FROM $oo,
                $ppx2: respond_GC_coursename            FROM $pp,
                $oox3: request_GC_address               FROM $oo,
```

```
                $ppx3: respond_GC_address                FROM $pp,
                $oox4: request_GC_city                   FROM $oo,
                $ppx4: respond_GC_city                   FROM $pp,
                $oox5: request_GC_state                  FROM $oo,
                $ppx5: respond_GC_state                  FROM $pp,
                $oox6: request_GC_zip                    FROM $oo,
                $ppx6: respond_GC_zip                    FROM $pp,
                $oox7: request_GC_phone                  FROM $oo,
                $ppx7: respond_GC_phone                  FROM $pp,
                $oox8: request_GC_description            FROM $oo,
                $ppx8: respond_GC_description            FROM $pp,
                $oox9: request_GC_slope                  FROM $oo,
                $ppx9: respond_GC_slope                  FROM $pp,
                $oox10: request_GC_fees                  FROM $oo,
                $ppx10: respond_GC_fees                  FROM $pp,
                $oox11: request_GC_requirements          FROM $oo,
                $ppx11: respond_GC_requirements          FROM $pp

        DO
                ADD $oox1 PRECEDES $ppx1;
                ADD $oox2 PRECEDES $ppx2;
                ADD $oox3 PRECEDES $ppx3;
                ADD $oox4 PRECEDES $ppx4;
                ADD $oox5 PRECEDES $ppx5;
                ADD $oox6 PRECEDES $ppx6;
                ADD $oox7 PRECEDES $ppx7;
                ADD $oox8 PRECEDES $ppx8;
                ADD $oox9 PRECEDES $ppx9;
                ADD $oox10 PRECEDES $ppx10;
                ADD $oox11 PRECEDES $ppx11;


        OD;
OD;


/* COORDINATE 22: Interaction between the TT IAA and the Tee Times ILF, and nested COORDINATE with
10 ADDs representing 10 DETs */


COORDINATE      $qq: request                     FROM TT,
                $rr: respond1                    FROM Teetimes_ILF

DO

        COORDINATE


                $qqx1: request_TT_id             FROM $qq,
                $rrx1: respond_TT_id             FROM $rr,
```

```
                $qqx2: request_TT_coursename            FROM $qq,
                $rrx2: respond_TT_coursename            FROM $rr,
                $qqx3: request_TT_date_repeating        FROM $qq,
                $rrx3: respond_TT_date_repeating        FROM $rr,
                $qqx4: request_TT_teetime               FROM $qq,
                $rrx4: respond_TT_teetime               FROM $rr,
                $qqx5: request_TT_no_players            FROM $qq,
                $rrx5: respond_TT_no_players            FROM $rr,
                $qqx6: request_TT_no_holes              FROM $qq,
                $rrx6: respond_TT_no_holes              FROM $rr,
                $qqx7: request_TT_golfer_name           FROM $qq,
                $rrx7: respond_TT_golfer_name           FROM $rr,
                $qqx8: request_TT_credit_card_type      FROM $qq,
                $rrx8: respond_TT_credit_card_type      FROM $rr,
                $qqx9: request_TT_credit_card_number    FROM $qq,
                $rrx9: respond_TT_credit_card_number    FROM $rr,
                $qqx10: request_TT_phone_number         FROM $qq,
                $rrx10: respond_TT_phone_number         FROM $rr


        DO
                ADD $qqx1 PRECEDES $rrx1;
                ADD $qqx2 PRECEDES $rrx2;
                ADD $qqx3 PRECEDES $rrx3;
                ADD $qqx4 PRECEDES $rrx4;
                ADD $qqx5 PRECEDES $rrx5;
                ADD $qqx6 PRECEDES $rrx6;
                ADD $qqx7 PRECEDES $rrx7;
                ADD $qqx8 PRECEDES $rrx8;
                ADD $qqx9 PRECEDES $rrx9;
                ADD $qqx10 PRECEDES $rrx10;


        OD;
OD;



/* COORDINATE 23: Interaction between the TT IAA and the Scoreboard ILF,
and nested COORDINATE with 5 ADDs representing 5 DETs */


COORDINATE          $ss: request            FROM TT,
                    $tt: respond2           FROM Scoreboard_ILF

DO

        COORDINATE
```

```
                $ssx1: request_scoreboard_golfer_name          FROM $ss,
                $ttx1: respond_scoreboard_golfer_name          FROM $tt,
                $ssx2: request_scoreboard_coursename           FROM $ss,
                $ttx2: respond_scoreboard_coursename           FROM $tt,
                $ssx3: request_scoreboard_date                 FROM $ss,
                $ttx3: respond_scoreboard_date                 FROM $tt,
                $ssx4: request_scoreboard_slope                FROM $ss,
                $ttx4: respond_scoreboard_slope                FROM $tt,
                $ssx5: request_scoreboard_score                FROM $ss,
                $ttx5: respond_scoreboard_score                FROM $tt

        DO
                ADD $ssx1 PRECEDES $ttx1;
                ADD $ssx2 PRECEDES $ttx2;
                ADD $ssx3 PRECEDES $ttx3;
                ADD $ssx4 PRECEDES $ttx4;
                ADD $ssx5 PRECEDES $ttx5;

        OD;
OD;


/* COORDINATE 24: Interaction between the TT IAA and the Merchandise EIF and
nested COORDINATE with 3 ADDs representing 3 DETs */


COORDINATE      $uu: request                   FROM TT,
                $vv: respond3                  FROM Merchandise_EIF

DO

        COORDINATE

                $uux1: request_Merch_product_name          FROM $uu,
                $vvx1: respond_Merch_product_name          FROM $vv,
                $uux2: request_Merch_price                 FROM $uu,
                $vvx2: respond_Merch_price                 FROM $vv,
                $uux3: request_Merch_picture               FROM $uu,
                $vvx3: respond_Merch_picture               FROM $vv

        DO
                        ADD $uux1 PRECEDES $vvx1;
                        ADD $uux2 PRECEDES $vvx2;
                        ADD $uux3 PRECEDES $vvx3;


        OD;
OD;
```

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